# PREDICTING READING ACHIEVEMENT IN CHILDREN: THE SIGNIFICANCE OF NAMING SPEED, PHONOLOGICAL AWARENESS, COGNITIVE ABILITY, PROCESSING SPEED, AND NEUROANATOMY

By

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This study investigated the relationship among behavioral and neuroanatomical predictors of reading achievement in a group of school-age children. Specifically, relationships between naming speed and other predictors of reading (i.e., phonological awareness, cognitive ability, and processing speed) were investigated to determine how these variables influence naming speed's prediction of reading achievement. In addition, this study examined specific neuroanatomical regions and their relationship to these predictors. A sample of 57 children, between the ages of 7 and 11 years, were administered three measures of naming speed (i.e., RAN Colors, Numbers, and Letters tasks), two measures of phonological awareness (i.e., the Elision and the Lindamood Auditory Conceptualization tests [LAC]), a measure of cognitive ability (Woodcock Johnson-Test of Cognitive Ability-Revised), a battery of elementary cognitive tasks

(Visual Inspection Time [IT], and Simple, Choice, and Odd-Man-Out Reaction Time [RT]), and three subtests from the Woodcock-Johnson Tests of Achievement-Revised to assess reading skills and performance. In addition, all participants received a magnetic resonance image (MRI) of their brain to measure specific neuroanatomical regions, including surface area of the pars triangularis, planum temporale and parietale, Heschl's gyrus, and the corpus callosum. Volumetric measurements were also made of the anterior lobe of the cerebellum and the cerebrum.

There were three major findings in this study. First, consistent with previous research, the results of this study indicate significant contributions of both naming speed and phonological awareness to the prediction of reading achievement. However, in this study, phonological awareness emerged as the strongest predictor overall, with a limited contribution from naming speed, for all of the specific reading skills assessed. Second, the results suggest that cognitive ability is an important predictor of reading achievement and may share some overlapping variance with naming speed. In addition, the relationship between naming speed and reading appears unrelated to processing speed.

Finally, the neuroanatomical findings in this study suggest significant relationships among regions in the brain and predictors of reading achievement. However, it is more likely that the variability in reading skill can be better accounted for by a combination of behavioral and biological factors. Implications for future research are discussed.

# CHAPTER 1
# INTRODUCTION

The general consensus among researchers is that phonological processing deficits underlie dyslexic readers' failure to acquire adequate word recognition skills (Wolf & Bowers, 2000). The assumption of a phonological core deficit (i.e., difficulty representing the sound structure of words and the inability to learn decoding principles) underlies intervention efforts with children diagnosed with reading disability. Despite the considerable amount of progress that has been made in phonology based research, certain aspects of dyslexia continue to elude the best theoretical explanations and interventions based on this single core-deficit hypothesis. More than a decade ago, Rudel (1985) cautioned that there are poor readers who slip through diagnostic batteries because they have adequate to good phonological decoding skills. Others (e.g., Blachman, 1994; Torgesen, Wagner, & Rashotte, 1994) have referred to these poor readers as "treatment resistors" who do not respond favorably to well-constructed, phonological based interventions.

Over the last several years, researchers have begun to diverge from a strict version of the phonological based view of reading deficits and have attempted to explain the consistent presence of naming speed deficits in impaired readers and their relationship to reading failure (Wolf & Bowers, 2000). The focus on naming speed stems from work in the neurosciences begun by Geschwind (1965) and further developed by Denckla and Rudel (1974, 1976a, 1976b). Denckla and Rudel created a series of continuous naming

speed tasks, called Rapid Automatized Naming (RAN) tests that have been used as a prototype for measuring serial naming speed or rapid naming. A substantial body of research supports the finding that children and adults with dyslexia are slower at accessing and retrieving verbal labels for visually presented stimuli than normal readers (Manis, Doi, & Bhadha, 2000; Semrud-Clikeman, Guy, Griffin, & Hynd, 2000; Wiig, Zureich, & Chan, 2000; for review, Wolf, Bowers, & Biddle, 2000). The relation between naming speed and reading achievement is so robust that performance on the task is sometimes used as a basis for identifying subgroups of dyslexic readers (Badian, 1997; Wolf & Bowers, 1999).

This study aims to further understanding of the relation between naming speed and reading. Rapid naming involves a variety of processes that overlap with reading, including but not limited to attention, visual recognition, access to phonological codes, and articulation (Manis, Seidenberg, & Doi, 1999). Although research to date has explored links between some of these component processes and naming, both empirical and theoretical questions concerning the relation between naming speed and reading remain.

First, is naming speed strongly associated with reading achievement, independent of phonological awareness? It is well established that phonological skills are strongly correlated with reading (Lyon, 1995; Share, 1995; Stanovich, 1988; Stanovich & Siegel, 1994; Torgesen et al., 1994; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Vellutino & Scanlon, 1987; Wagner & Torgeson, 1987). The speed of naming written symbols clearly has phonological components (e.g., accessing and articulating the symbol names). Thus, it is possible that the correlations between naming speed and reading

simply provide additional support for the importance of phonological knowledge in reading. However, recent studies suggest that naming speed and other measures of phonological skill account for independent sources of variance in reading (Cornwall, 1992; Cutting, Carlisle, & Denckla, 1998; Felton & Brown, 1990; Manis et al., 2000; Wagner, Torgesen, Laughon, Simmons, & Rashotte, 1993; Wagner, Torgesen, & Rashotte, 1994; Wimmer, 1993). These findings suggest that "naming speed's internal complexity go beyond phonological processes" and that "naming speed should not be subsumed under phonology" (Wolf et al., 2000, p. 393). Because the RAN task is frequently used in the language assessment of children, these conflicting views should be investigated further.

Second, is naming speed associated with "nonphonological" predictors of reading, such as cognitive ability and processing speed, and if so, how does this affect naming speed's relationship with reading achievement? Elementary cognitive tasks (ECTs) are commonly used to assess cognitive processing speed. Two frequently used ECTs are Inspection Time (IT) and Reaction Time (RT). Only two studies to date have examined differences between learning disabled and regular readers on tests of IT (Kranzler, 1994; Whyte, Curry, & Hale, 1985). Whyte et al. (1985) compared 7 dyslexic and 7 normal reading boys (aged 9-11 years) on an IT task. They found the dyslexics required significantly longer ITs than the normal readers. Unlike Whyte et al., Kranzler (1994) reported no differences between learning disabled children and controls (matched for age and sex) on the IT task. However, the relationship between IT and reading achievement was not examined in these studies. Only a few studies have examined the correlation between learning disabled and regular readers on tests of RT and reading achievement

(Nicolson & Fawcett, 1994; Stringer & Stonovich, 2000). When Nicolson and Fawcett (1994) compared the RTs of participants with reading disabilities to those of chronological age controls (ages 11-15), differences were found only on the Choice RT condition of the task. Stringer and Stanovich (2000) reported a significant relationship between RT and reading achievement in a sample of self-referred adults (ages 16-54); in their study they found this relationship was largely due to variance shared with phonological awareness and IQ. RT explained little variance after phonological awareness had been partialled out and almost no unique variance after phonological awareness and general cognitive ability had been removed. In addition, the overlap in the variance of RT and phonological processing was almost entirely due to the variance shared with IQ. Stringer and Stanovich's study included only a sample of 81 adult participants; these investigations need to be replicated in a sample of children. More importantly, the knowledge of how naming speed relates to these and other cognitive variables is needed to explain the relationship between naming speed and reading achievement in children.

Finally, what is the relationship between neuroanatomy and specific predictors of reading, such as naming speed? In addition to understanding the various behavioral processes involved in reading, it is also useful to examine the neurobiological systems underlying language function. Using modern neuroscience techniques, researchers can localize and measure the various brain regions thought to subserve language. Although research has demonstrated the core structures generally involved in the language process (e.g., inferior frontal gyrus [also referred to as Broca's area in the left hemisphere], planum temporale, Heschl's gyrus, among others), few studies have used imaging

techniques to explore these areas and their role in predicting specific aspects of reading (Eden, Jones, Zeffiro, & Joseph, 2000; Misra, Katzir-Cohen, Clark, Wolf, & Poldrack, 2001). Additional research is needed to further explore these relationships.

This study addresses these issues by examining the association between naming speed and reading achievement among a group of normal children. Specifically, relationships between naming speed and other predictors of reading (i.e., phonological awareness, cognitive ability, and processing speed) will be investigated to determine how these variables influence naming speed's prediction of reading achievement. In addition, this study will also examine specific neuroanatomical regions and their relationship to these predictors. The next chapter presents a review of the literature relating to these research questions.

# CHAPTER 2
# REVIEW OF THE LITERATURE

Learning to read is a task that poses considerable difficulty for almost 10% of the school-age population (Mann, 1998). Children with reading and spelling problems are diagnosed as dyslexic or reading disabled because their reading problems cannot be explained by a lack of general intelligence, motivation, or adequate classroom experience (Stanovich, 1986). Psychologists, educators, and neurologists have all, in one way or another, tried to identify the basis of early reading difficulty. Their efforts have been guided by some basic assumptions about reading and the demands that it makes upon children's perceptual and cognitive abilities. Reading involves perceiving, recognizing, remembering, and interpreting the various letters and the words, sentences, and paragraphs which they form. Readers cannot interpret the letters, words, sentences, and paragraphs unless they make some type of mapping between written and spoken language (Mann, 1998).

## The Link Between Written and Spoken Language

All writing systems use symbols to represent the spoken units of language. The English language uses an alphabet to represent phonemes, the minimal units of sound that we refer to as consonants and vowels (Mann, 1998). However, the English language does not provide the one-to-one mapping of letter to phonemes that one finds in Spanish, for example. The mapping between letters and phonemes often requires a deeper, more abstract level of linguistic representation, which has often been referred to as

morphophonological because it combines phonemes (units of sound) and morphemes (units of meaning) (Mann, 1998). According to linguistic theory, when we produce or perceive language, we convert the morphophonological representations of the words in our lexicons into the less abstract, phonetic representations with which we are more familiar (i.e., the words we speak and hear). This conversion involves an ordered series of phonological rules that alter, insert, or delete phonemes. We manipulate morphophonological representations, morphemes, and phonemes without being aware of their existence (Mann, 1998).

Alphabets may have clear advantages, but they nonetheless pose an obstacle for poor readers. Poor readers might have problems distinguishing and remembering the various letter shapes or processing spoken language. Poor readers might also lack an awareness of the linguistic units that the written words represent. In order for readers of English to be aware of the relationship between printed and spoken words, they must be aware of phonemes. They must be sensitive to the fact that words can be broken down into phoneme-sized units (Mann, 1998).

## Phonological Deficits and Reading

Many researchers agree that phonological processing problems are a primary source of reading disabilities (Wolf & Bowers, 1999). Researchers supporting this position believe that phonemic insensitivity and other phonological-based problems are the principal basis for later impaired word recognition, which underlies most reading disability. This theory, also referred to as the phonological-core deficit hypothesis, suggests that dyslexic individuals have a highly specific deficit in the phonological language domain which may lead to problems in short-term memory, sound segmentation

and categorization, sound blending, and consequently, to problems in reading and spelling (Bradley & Bryant, 1983; Lyon, 1995; Stanovich & Siegel, 1994; Torgesen et al., 1994; Vellutino & Scanlon, 1987; Wagner et al., 1994). The kinds of phonological processing skills and knowledge that have been most frequently studied include phonological awareness, phonological memory, and the rate of access for phonological information (Torgesen et al., 1994).

Phonological awareness is generally defined as one's sensitivity to, or explicit awareness of, the phonological structure of the words in one's language (Torgesen et al., 1994). According to Blachman (2000, p. 483), "this awareness develops gradually over time and has a causal reciprocal relationship to reading." It is measured by tasks that require children to identify, isolate, or blend the individual phonemes in words. At a beginning level, phonological awareness is frequently assessed by tasks that require sensitivity to rhyme or alliteration (i.e., the repetition of the same first sound or letter). A typical task at this level might involve identifying which of three words begins (or ends) with the same sound as a target word. More difficult measures of phonological awareness require explicit manipulation or separation of the sounds in words. For example, children might be asked to pronounce the first sound of a word in isolation, or they might be asked to indicate the word that is produced if the /p/ sound is deleted from the word /pat/. Usually, children do not attain full development of explicit phonological awareness until reading instruction begins, in first grade, although they can frequently perform quite well on simpler measures of phonological sensitivity in kindergarten (Torgesen et al., 1994).

Children who are relatively strong in phonological awareness in kindergarten, before reading instruction begins, typically learn to read more easily than those with relatively delayed development in this area (Bradley & Bryant, 1985; Byrne, Freebody, & Gates, 1992; Felton & Wood, 1989; Stanovich, Cunningham, & Cramer, 1984). Correlations between performance on phonological awareness tasks in kindergarten and word-reading skills at the end of first grade usually fall within the range of .40 to .60. These empirical relationships are consistent with the idea that some degree of awareness of the phonological structure of words helps to make learning to read a more understandable task for young children (Liberman, Shankweiler, & Liberman, 1989).

Phonological memory is typically assessed by tasks that require the brief, verbatim retention of nonmeaningful sequences of verbal items (Torgesen et al., 1994). The most commonly accepted explanation for difficulties on this type of task, generally referred to as memory span tasks, involves problems in mentally representing the phonological features of language (Baddeley, 1986; Dempster, 1985; Hansen, 1989; Torgesen, Kistner, & Morgan, 1987). A variety of converging evidence suggests that the representations, or codes, used to store verbal material (e.g., digits, letters, words, or pronounceable nonwords) on memory span tasks requiring immediate, verbatim, and ordered recall are composed primarily of the phonological features of the stimuli. Difficulty with this type of task is one of the most frequently reported cognitive characteristics of children with severe reading disabilities (Baddeley, 1986; Hulme, 1988; Jorm, 1983; Torgesen, 1985). Performance on memory span tasks in kindergarten is also predictive of individual differences in word reading skill at the end of first grade (Jorm, Share, Maclean, & Matthews, 1986; Mann & Liberman, 1984).

Children's ability to easily and rapidly access phonological information that is stored in long-term memory has typically been assessed in the reading literature by the RAN. Denckla and Rudel (1974, 1976a, 1976b) first introduced this type of task as a way of predicting and understanding individual differences in reading. The RAN procedure requires children to name a series of 40 to 50 familiar items, such as digits, letters, colors, or pictured objects as quickly as possible (Denckla & Rudel, 1976b; Wagner & Torgesen, 1987). An extensive body of research over the past two decades has shown that the speed of naming familiar visual symbols is strongly associated with reading development (Badian, 1997; Blachman, 1984; Bowers, 1995; Denckla & Rudel, 1976b; Wagner et al., 1994; Wolf, Bally, & Morris, 1986; Wolf et al., 2000). Scarborough and Domgaard's (1998) review of longitudinal studies using the RAN task in the period from kindergarten to the third grade revealed that naming speed was at least as strongly related to later reading skills as other leading predictor variables such as letter name knowledge and phonological awareness. Naming speed deficits are also widely observed in samples of reading disabled individuals, ranging from the first grade to adulthood (Bowers, 1995; Felton & Brown, 1990; Meyer, Wood, Hart, & Felton, 1998; Wolf et al., 1986).

## The Double Deficit Hypothesis

Although most of the current conceptualizations of naming speed consider it part of a broad class of phonological processes (Share, 1995; Stanovich, 1988; Torgesen et al., 1997; Wagner & Torgesen, 1987), other researchers are investigating whether naming speed deficits represent a distinct, second core deficit in dyslexia that is largely independent of phonology (Bowers & Wolf, 1993; Felton & Brown, 1990; Wolf, 1991,

1997; Wolf & Bowers, 1999). These researchers have proposed that although rapid naming may share some variance with other tests of phonological skill, the RAN task taps other nonphonological processes that are important in reading development, such as speed of processing or sensitivity to temporally ordered information. Wolf and Bowers' (Bowers & Wolf, 1993; Wolf & Bowers, 1999) double-deficit hypothesis proposes that there are deficits associated with the timing of various reading subprocesses such as letter recognition and serial scanning of print that are independent of deficits in phonological skill. The RAN task is useful because it taps into some of these nonphonological processes. This conceptualization posits three impaired reader subtypes: two subtypes with single deficits in either phonological processing or naming speed and one double-deficit subtype. The double-deficit subtype is composed of the most impaired readers across all dimensions of reading, potentially because the co-occurrence of phonological and naming speed deficits allows limited compensatory routes (Wolf & Bowers, 2000).

Two kinds of evidence support Wolf and Bowers' double-deficit hypothesis. First, there are generally modest rather than strong interrelationships between naming speed and the broad group of phonological based tasks (e.g., Blachman, 1984; Cornwall, 1992; Felton & Brown, 1990; Mann, 1984). Phonemic awareness tasks have relatively weak correlations with naming speed, whereas phonological (nonword) decoding accuracy and latency have stronger relationships (Wolf & Bowers, 1999). The nonword decoding variables have contributions from both phonemic awareness and naming speed. Second, there are independent, differential contributions of both phonemic awareness and naming speed tasks to the variance in word identification (accuracy and latency),

orthographic skill, fluent text reading, and comprehension (Wolf & Bowers, 1999). Examples of these studies are discussed in greater detail in the following paragraphs.

Blachman (1984) and Mann (1984) found nonsignificant, modest relationships between early phonemic awareness and rapid naming tasks in kindergarten and first grade students. In a study designed to evaluate the presence of a large, general, phonological factor in a reading-risk population, Felton and Brown (1990) found no significant correlations between naming speed and all measures of phonological processes tested (i.e., four phonological awareness tasks, one phonetic recoding in memory task, and one other task classified as phonological recoding). Cornwall (1992) reported a modest relationship ($r = .35$, $p < .05$) between naming speed and one measure of phonological awareness (phoneme detection) in a reading impaired population and independent prediction capabilities for both. Cornwall (1992) concluded that "these abilities may represent unique aspects of the reading process, as opposed to an overall phonological ability" (p. 537). In a sample of profoundly impaired readers, Goldberg, Wolf, Cirino, Morris, and Lovett (1998) found no significant relationships between phoneme elision, blending tasks, and serial naming.

Results from full classroom samples, unselected for reading achievement, differ somewhat from samples of reading disabled children. For example, in samples from third grade classrooms unselected for reading skill, Bowers, Sunseth, and Newby-Clark (1998) found that RAN digits and phoneme deletion correlated .40 while still maintaining independent relationships to various reading skills. Wagner et al. (1993), using data from randomly selected children from regular classrooms, reported a somewhat lower correlation ($r = .35$) in a second grade classroom between measures of serial naming and

phonological awareness. In each of these studies, data were consistent with an earlier confirmatory factor analysis by Wagner et al. that described a model consisting of "two underlying abilities" in phonological awareness and in code retrieval (naming speed) as best representing their 1987 and 1993 databases. Wagner et al. (1993) reported "a single underlying source of individual differences accounted for performance on the phonological awareness tasks [and] a different underlying source of individual differences was found for the phonological code retrieval [naming speed] tasks" (p. 85).

Cross linguistic results are also supportive of Wolf and Bowers' hypothesis. Wimmer (1993) found little relationship between naming speed and three measures of phonological awareness processes in a group of second to fourth grade German participants. Naeslund and Schneider (1991) found a modest but significant ($r = .37$) relationship between naming speed and phonological awareness tasks in a study of young German readers. The bulk of reported findings across average and impaired readers, several age groups, and three languages (English, German, and Dutch) is consistent with only modest interrelationships between naming speed and a variety of early phonological awareness measures. Findings in English, German, and Dutch all indicate the partial independence of naming speed measures from phonological awareness measures in predicting word-recognition performance (e.g., Blachman, 1984; Bowers, 1995; Bowers & Swanson, 1991; Felton & Brown, 1990; Mann & Liberman, 1984; Meyer et al., 1998; Naeslund, 1990; Naeslund & Schneider, 1991; van den Bos, 1998; Wimmer, 1993).

Research on the differing patterns in the relationships of phonemic awareness and of naming speed to the varying reading subskills (e.g., accuracy and latency) is found in a series of studies (Blachman, 1984; Bowers, 1993, 1995; Bowers, Steffy, & Tate, 1988;

Bowers & Swanson, 1991; Cornwall, 1992). These researchers found phonological awareness tasks strongly predictive of word and nonword identification, but not of word and text reading speed. Phonological awareness uniquely predicted word attack (nonword reading), with naming speed's smaller contribution overlapping with phonemic skill. Naming speed was independently related to word identification (accuracy and latency) for moderate and high word frequency. Naming speed and reading comprehension have been found to be significantly but indirectly related because of the shared variance of comprehension with word identification accuracy and speed (Bowers & Swanson, 1991; Kail & Hall, 1994; Spring & Davis, 1988). Cornwall (1992) found a pattern of results similar to Bowers and Swanson's (1991). Phonological awareness added significantly to the variance in word attack and comprehension, and naming speed measures added significantly to the variance in word identification, prose passage speed, and prose passage accuracy. Manis and Doi (1995) conducted a regression analysis with a clinical sample by using word reading speed and nonsense word decoding as predictor variables of six reading measures. They found that both variables explained significant, independent variance in the prediction of reading measures. Doi and Manis (1996) extended these results to show the same pattern when symbol naming speed, rather than word-reading speed, was a predictor of orthographic ability.

Torgesen et al. (1997) reported a longitudinal study in which children's fourth and fifth grade reading achievement were correlated with second and third grade vocabulary, phonemic awareness, and rapid naming measures. They also found the expected pattern of greater unique contributions by phonemic awareness than rapid naming to later word

analysis and greater contributions by rapid naming than phonemic awareness to orthographic accuracy and speed, as well as fifth grade reading speed.

## Naming Speed Processes

A rationale for emphasizing the differences between naming speed and phonology is embedded in the complex cognitive structure of naming (Wolf et al., 2000). Naming speed is conceptualized as a complex group of attentional, perceptual, conceptual, memory, phonological, semantic, and motoric subprocesses that have precise, rapid timing requirements within and across all components (Wolf et al., 2000). The typical naming speed task requires the participant to name visually presented symbols in a given set (e.g., colors, letters, numbers, or objects) as quickly as possible. Unlike confrontation naming tests in which each pictured object is presented one at a time, in serial naming speed tasks symbols are presented in succession and repeated often up to 10 times in an array; the number of symbols is usually restricted to five in a set (Wolf & Bowers, 1999).

Wolf and Bowers (1999) describe a model of letter naming that illustrates how serial naming speed's internal complexity go beyond phonological processes. Briefly, rapid naming requires (a) attention to the stimulus; (b) bihemispheric visual processes that are responsible for detection of the initial features of the stimulus, visual discrimination, and letter-pattern identification; (c) integration of the visual features and pattern information with the stored orthographic representations; (d) integration of the visual information with the stored phonological representations; (e) access and retrieval of phonological labels; (f) activation and integration of semantic and conceptual information; and (g) motoric activation leading to articulation. Precise rapid timing on

the task is critical for both the efficiency of operations within individual subprocesses and for integrating across them (Wolf & Bowers, 1999).

Demand for speed differs according to the specific characteristics of the symbols used in the rapid naming task. For example, letters are typically processed more rapidly than other stimuli (e.g., colors or objects), because they constitute a highly constrained category and are capable of being processed relatively "automatically" (Wolf, 1991; Wolf & Bowers, 1999).

Within the model's description, the phonological process' role in naming speed tasks is essential. Phonological processes are used to activate the stored phonological representations and to access and retrieve phonological labels. Other verbal tasks, such as semantic fluency and expressive vocabulary tasks, require the same phonological processes, however, these tasks are rarely categorized as phonological tasks (Wolf & Bowers, 1999). The greater emphasis on other operations in these tasks has led them to be categorized as semantic and vocabulary tasks, rather than as part of the phonological family of tasks. Therefore, Wolf and Bowers (1999) argue that naming speed's particular emphasis on both processing speed and the integration of visual, perceptual, and higher level cognitive and linguistic processes command a separate categorization of their own. Importantly, these subprocesses are also utilized in reading at a more complex level of integration with comprehension processes. In support of this view, Denckla (1998) contends that naming speed tasks represent a microcosm of reading. Denckla suggests studying children's performance on rapid naming tasks provides an opportunity to examine how rapid visual-verbal connections, essential to reading, are completed in the developing child's system. Thus, early deficits in basic naming speed could alert

researchers to future weaknesses in the later developing reading system and may also play a causal role (Wolf & Bowers, 1999).

Cognitive Processing Speed

Consistent with the view that there are various subprocesses related to naming speed and hence, reading, there is a growing literature on the extraphonological sources of variance in reading achievement (Stringer & Stanovich, 2000). Two such candidates of nonphonological processes are cognitive processing speed and general cognitive ability.

Elementary cognitive tasks (ECTs) are used to measure processing speed. Performance on ECTs, simple tasks of mental speed, are intended to measure a few simple cognitive processes, minimizing the amount of specific knowledge or information content. Simple tasks involve stimulus apprehension, discrimination, choice, visual search, scanning of short-term memory, and retrieval of information from long-term memory (Eysenck, 1994). ECTs typically require minimal past-learned information content, thus reducing the effects of experience or environment. Most of the tasks are so simple that every participant in the study can perform the required responses very easily, with few errors. If any particular knowledge content is required to perform the task, preliminary practice trials are given to ensure that all subjects can perform the task (Jensen, 1998). Many different ECTs exist; two of interest to this study are Inspection Time (IT) and Reaction Time (RT).

IT is one of several ECTs used to measure individual differences in the "temporal rate at which information is taken in for processing" (Nettelbeck, 1987, p. 295). IT involves a simple discriminative judgment that almost any individual can make, across a

wide variety of ages and cognitive ability. The procedure for measuring IT proposed by Vickers, Nettelbeck, and Wilson (1972) is still used today, although a variety of discrimination tasks and procedural variations have been proposed. Currently, most IT studies involve visual, tactile, or auditory discriminations.

The visual form of the IT task measures the minimum amount of exposure time the brain needs for a simple visual discrimination (e.g., between lines of differing lengths). This ECT is unique in that it does not require a motor or output component. In this task, the subject is told to fixate on a target point (e.g., a small red dot) in the center of a display screen. After three seconds, the red dot disappears and the test figure appears immediately in the center of the screen. After an interval of time (e.g., 200 ms), a masking figure appears in exactly the same location as the test figure, completely covering it. The subject indicates (by pressing one of the two thumb buttons held in each hand) whether the long leg of the test figure is on the left side or on the right. The subject can take as much time as necessary to make this decision. The time interval between the appearance of the test figure and the masking figure varies systematically from trial to trial. The computer program is reactive, taking account of the subject's correct and error responses on each trial, until it stabilizes at the point where the subject responds correctly 90% of the time (Barrett, Petrides, & Eysenck, 1998). The length of time at the point of 90% accuracy is the subject's IT.

IT measures predict reliable individual differences, which have been found to be substantially correlated with cognitive ability. In a meta-analysis of over 90 studies with adults and children, Grudnik and Kranzler (2001) reported the best estimate of the relationship between IT and intelligence is a correlation around -.50.

Two studies to date have investigated reader group differences on tests of IT (Kranzler, 1994; Whyte et al., 1985). Kranzler (1994) reported no differences between participants with learning disabilities and controls using the visual form of the IT task. However, no study has investigated the relationship between performance on the IT task and reading achievement.

Although the literature on reader group differences on tests of RT is more extensive, there is a range of findings across the perceptual and motoric areas (see for review, Wolf et al., 2000). As noted by Wolff (1993) the range of these findings cannot be explained by a simple, across the board RT explanation. No RT differences appear on single task conditions at the most basic level of perceptual detection; rather, perceptual timing differences in dyslexic readers seem to occur when some aspect of choice and integration of more than one set of subprocesses are required. Moore, Kagan, Sahl, and Grant (1982) investigated the differences between average and dyslexic readers on an extensive array of cognitive, perceptual, and motor tasks that included 14 decision time tasks. They concluded that, "when the task is very simple, decision times for retarded readers and normal readers tend to be very similar, but the differences between the two groups increase when the task is much more complex" (p. 91).

RT tasks can vary from simple responses to illuminated lights on a panel to more complex measures, requiring the retrieval of spatial information from long-term memory. RT is defined by the amount of time between the appearance of the stimulus and the time it takes the subject to "react" to it (e.g., releasing a "home" button). In simple forms of the RT task (Simple RT), the subject does not have to discriminate between different stimuli or response alternatives. Simple RT requires the individual to make only one

response to the apprehension of the stimulus. Other, more complex forms of RT involve choice tasks, such as Choice RT or Odd-Man-Out RT (Diascro & Brody, 1994; Frearson & Eysenck, 1986). Choice RT requires the individual to discriminate between stimuli and make a choice between two or more different response alternatives. The Odd-Man-Out form of the task is identical to the Choice RT procedure, however, instead of one button lighting up, three lights go "on" simultaneously. An individual performing the Odd-Man-Out task utilizes all eight buttons on the apparatus. Their locations are random and unpredictable on each trial, except that two of the lights are always in closer proximity to one another than the third light, the "Odd-Man-Out." Studies have shown that RT tasks correlate about -.20 to -.40 with intelligence (Rijsdijk, Vernon, & Boomsma, 1998; Vernon, 1993).

Only a few studies have examined the correlation between learning disabled and regular readers on tests of RT and reading achievement (Catts, Gillispie, Leonard, Kail, & Miller, 2002; Nicolson & Fawcett, 1994; Stringer & Stanovich, 2000). Nicolson and Fawcett (1994) compared reader group differences on both simple and choice forms of the RT task and reading achievement. Their findings suggested an extraphonological source of variance in reading achievement could only be explained by Choice RT. In their study, participants heard a tone to which they responded to as quickly as possible with a key press (Simple RT). When the RTs of the participants with reading disabilities were compared to those of chronological age controls, no differences were found. In the second RT task, the participants heard two tones (i.e., one high pitched and the other low) and were instructed to press the key only in response to one of them (a selective Choice RT task). In this paradigm, reading disability was significantly associated with RT.

The results of Nicolson and Fawcett's study suggest that a nonphonological deficit, namely a processing speed deficit, independently contributes to reading difficulties. The elements of choice and precise, temporal coordination, both of which contribute to the system's cognitive load, appear necessary for the timing deficits to be evidenced (Wolf et al., 2000).

General Cognitive Ability

Although the results of Nicolson and Fawcett's (1994) study appear to shed light on the associated variance in reading due to processing speed deficits, they do not address overlapping sources of variance that may be due to general cognitive ability. Stringer and Stanovich (2000) were inspired by the work of Nicolson and Fawcett (1994) and sought to examine whether RT was an independent (of phonological variance) predictor of reading achievement in their sample and whether any overlapping or nonoverlapping variance was additionally independent of general cognitive ability. Using several different models of examining overlapping variance (e.g., hierarchical regression analysis and path analysis), Stringer and Stanovich found that the zero-order correlation between RT and word recognition ability was largely due to variance shared with phonological awareness and general cognitive ability. That is, RT explained little variance in reading achievement after phonological awareness had been partialled out and almost no unique variance after phonological awareness and general cognitive ability had been partialled out. In addition, the overlap in the variance between RT and phonological processing was almost entirely due to variance shared with general cognitive ability. Although the results of this study replicated those of Nicolson and Fawcett (1994) concerning a significant correlation between RT and reading achievement, they found little evidence

that RT should be considered an extraphonological source of variance in reading achievement. It explained little variance in reading achievement after phonological awareness had been partialled out and almost no unique variance after phonological awareness and general cognitive ability had been partialled out. The overlap in the variance of RT and phonological processes was almost entirely due to variance in intelligence shared by both variables. Their results did not support a more distally related hypothesis of reading (e.g., as in hypotheses about timing deficits). However, Stringer and Stanovich's study consisted of adult "garden variety" poor readers, without aptitude/achievement discrepancies. The relation between RT and reading difficulties may be different in samples consisting of children or poor readers with both high and low levels of general ability.

Other studies have investigated the relationship between intelligence, rapid naming, and phonological awareness (Ackerman, Dykman, & Gardner, 1990; Bowers et al., 1988; Torgesen, Wagner, Simmons, & Laughon, 1990); however none has examined the relationship of these variables to cognitive processing speed. In all three of these studies, these authors reported significant relationships between naming speed and reading after controlling for verbal IQ. Inconsistent support has been given to the predictive ability of phonological awareness to reading achievement when it is examined with tests of intelligence and other processing variables (Cornwall, 1992).

Based on the results of these studies, more evidence is needed before any conclusions can be drawn about whether naming speed deficits represent a more systematic failure in timing processes or are due to variance in general cognitive ability.

No study to date has explored the overlapping variance in reading achievement due to rapid naming, processing speed, and general cognitive ability.

Socioeconomic Status

It is important to examine the effects of socioeconomic status (SES) in any study investigating the relationship between intelligence and other variables, such as reading achievement. Throughout the development of intelligence tests, there has been a consistent and robust relationship reported between measures of SES (e.g., parental occupation, levels of parental education, and median family income), and intelligence test scores (Kamphaus, 1993). The relationship between a family's SES and children's intelligence is about .33 (Sattler, 1992). Duncan, Brooks-Gunn, and Klebanov (1994) found family income correlated more highly with intelligence than did maternal education, ethnicity, and female headship of the household among the five year olds in their study.

The relationship between SES and reading achievement has also been documented in the literature. For example, Schonhaut and Satz (1983) reviewed 18 follow-up studies examining long-term outcomes for children with reading disabilities. They reported that SES was strongly related to the probability of developing a reading disorder, as well as the level of academic achievement attained. Telzrow (1987) reported that high SES may attenuate the long-term academic difficulties of children with learning disabilities with or without adequate intervention. Schonhaut and Satz suggest researchers who are examining variables that influence reading achievement should carefully control for the confounding effects of SES. Consistent with Telzrow's review, Cornwall (1992) found SES to be a significant predictor of the word attack and word

identification scores among the reading disabled subjects in her study. Based on these findings, the effects of SES will be considered in this study.

## Neuroanatomical Assessment of Reading

In addition to understanding the various behavioral processes involved in reading, researchers have also placed importance on examining the neurobiological systems underlying language function. By localizing and measuring the various brain regions thought to subserve language, researchers can yield important insights into how reading is accomplished and what structures may be involved in the various components of the process. Although most of these investigations have been done with adults and brain-damaged subjects, modern neuroscience offers an extraordinary opportunity to examine the relationship between the developing brain, its structure, and function in normal children (Andreasen et al., 1993; Joseph, Noble, & Eden, 2001).

### General Features of the Brain

Before discussing research relating brain function and reading, it is important to first understand the basic design features of the brain. The cerebral cortex is generally considered to be the seat of higher intellectual functions (Lynch, 1997). The cerebral cortex consists of two hemispheres, right and left, connected by a band of neural fibers called the corpus callosum, which mediates communication between the two sides. The cortex is composed of gray matter consisting of nerve bodies and their connections and is the most complex and organized area of the brain. The patterns of functional localization in the cortex are organized along two planes: (a) lateral which divides the right and left sides of the brain and (b) longitudinal which runs from the front to the back of the brain. The primary sensory and motor centers are homologously positioned within the cortex of

each hemisphere in a mirror image relationship and mediate the activities of the contralateral half of the body. The arrangement of visual and auditory cortex are more complex. The lateral plane is also helpful for differentiating the localization of primary cognitive functions and how information is processed in the brain. It is generally theorized that for right handed individuals, the left hemisphere is associated with a sequential-analytic-linguistic form of processing and mediates verbal transformations, receptive and expressive language, reading, writing, comprehension of verbal symbols, and the musculature of speech. The right hemisphere controls the parallel-holistic-spatial-nonlinguistic mode of processing and mediates visual and spatial transformations, processing and storage of visual information, tactile and visual recognition of shapes and forms, perception of directional orientation, copying, drawing, and musical ability (D'Amato, 1990). The longitudinal plane is important for dividing the brain into lobes and their functions, however, there are many overlapping areas (see Figure 2-1).

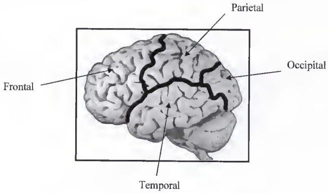


Figure 2-1 Lobes of the Cerebral Hemispheres

In addition to the lateral and longitudinal planes, the cortex is subdivided into functional areas and each assigned a Brodmann number (see Figure 2-2). For example, the primary visual area in the cortex is also called Brodmann's area 17 (Lynch, 1997; Obrzut, 1981).

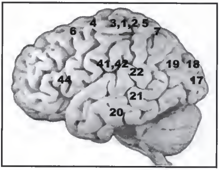


Figure 2-2 Selected Brodmann's Areas of the Cortex

Language and the Brain

The cerebral hemisphere that controls language is called the dominant hemisphere. In the vast majority of individuals, language functions are processed in the left hemisphere. Evidence of this is seen by the fact that brain lesions that adversely affect language are found in the left hemisphere in about 95% of cases (Lynch, 1997). Investigators have attributed language-specific processing to the areas in the brain that surround the sylvian fissure, known as the perisylvian areas (Joseph et al., 2001). Primary auditory input for language arrives at Heschl's gyrus, the primary auditory cortex, on the superior surface of the dominant (left) temporal lobe (see Figure 2-3). Heschl's gyrus projects, via corticocortical fibers, to its corresponding auditory association area cortex in the superior temporal gyrus. The posterior superior temporal

gyrus, or Wernicke's area, is a critical crossroad for much of language input and comprehension. Based on his work with patients who had been diagnosed with aphasia (i.e., total or partial loss of the ability to use or understand words), Wernicke proposed this area was specialized for auditory word recognition (Wernicke, 1887 as cited in Joseph et al., 2001). Wernicke's area is connected via a long white matter tract, the arcuate fasciculus, to Broca's area, a crucial area of the inferior frontal gyrus for language output to the primary motor cortex. Broca's area, including the dorsolateral prefrontal cortex, are generally associated with organization, manipulation, and the production of language, using grammar and syntax. Inferior parietal sites, such as the supramarginal gyrus and the angular gyrus have also been associated with written and spoken language comprehension (Friedman, Ween, & Albert, 1993; Joseph et al., 2001; Lynch, 1997).

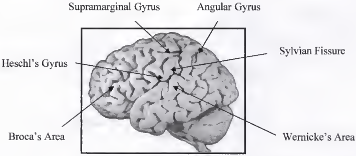


Figure 2-3 Regions Associated with Language in the Left Hemisphere

Today, researchers can infer brain function through several techniques: measuring electrical charges initiated by nerve cells (event related potentials, or ERPs), mapping specific functional areas in the cortex (magnetoencephalography, or MEG), observing changes in blood flow circulation (regional cerebral blood flow, or rCBF), measuring how nerve cells use energy (positron emission tomography, or PET), and measuring

structural (magnetic resonance imaging, or MRI) or functional (functional magnetic resonance imaging, or fMRI) details of the brain (Flowers, 1993). The next section presents an overview of research that has examined structures in the cortex related to language and the various components of the reading process. The structures that have received special attention and that are of particular interest to this study are the following: inferior frontal gyrus, planum temporale, Heschl's gyrus, corpus callosum, and the cerebellum.

Inferior Frontal Gyrus

The posterior region of the left inferior frontal gyrus is also commonly referred to as Broca's area, so named after Paul Broca (1861) who was the first to present clinical cases (called Broca's aphasics) in which brain damage to this area of the brain was associated with disordered speech and language. Typically, patients with Broca's aphasia have nonfluent speech, intact comprehension, and disordered repetition. Naming can also be poor in these individuals, but is often aided by contextual or phonetic prompting (Benson, 1993).

Today, researchers interested in the reading process have studied the morphology of the inferior frontal region extensively in normal and reading and language impaired individuals, due to its apparent association with the motor output component of speech. Researchers using MRI have reported abnormalities of this region among reading and learning impaired individuals. For example, Hynd, Semrud-Clikeman, Lorys, Novey, and Eliopulos (1990) found abnormal symmetry among children diagnosed with dyslexia compared to normal children ($N = 10$, matched for age and sex) and Jernigan, Hesselink, Sowell, and Tallal (1991) reported a significant difference among language and learning

impaired children and normal controls in the inferior frontal regions, with reversed direction of asymmetry among the language and learning impaired children. In a similar study, Gauger, Lombardino, and Leonard (1997) replicated and extended these results among a sample of 11 children with specific language impairment (SLI) and 19 controls (matched for age and sex). They reported Broca's area was significantly smaller in the left hemisphere of children with SLI and that these children were also more likely to have reversed asymmetry of language structures. In a recent study, Eckert et al. (2003) reported significantly smaller volumes of both the right and left inferior frontal gyrus (specifically the pars triangularis) in a group of dyslexic children ($n = 18$) compared to controls ($n = 32$, matched for age). In their study, Eckert et al. also examined the relationship between the volumes of the right and left pars triangularis and performance on oral and written language tests administered to these children. They found a significant correlation between the right pars triangularis and performance on the Elision task (Wagner, Torgesen, & Rashotte, 1999), a test used to measure phonological awareness ($r = .34$, $p < .05$) among the dyslexics and controls. In addition, Eckert et al. found significant correlations between both the right ($r = -.41$, $p < .05$) and left ($r = -.44$, $p < .05$) pars triangularis and performance on a measure of rapid naming. This is one of the first studies to suggest the right hemisphere may also play a role in differentiating the language abilities of these children.

Clark and Plante (1998) recently used MRI among a sample of normal adults to show a relationship between the sulcal morphology of this region and a family history of developmental language disorders. Their findings suggested an increased risk factor for developing language disabilities due to the statistical relationship found between the

presence of extra sulci in the frontal region and behavioral testing consistent with a diagnosis of the disorder. Because gyral patterns are prenatally determined, Clark and Plante suggest that their findings are consistent with the theory that altered prenatal development contributes to the expression of a developmental language disorder. Robichon, Levrier, Farnarier, and Habib (2000) recently measured Broca's area asymmetry among adult dyslexics and controls (matched for age) and found a more frequent symmetrical pattern in Broca's area in dyslexics and a correlation between this pattern and subjects' nonword reading performance. This result is consistent with studies using fMRI and PET that have suggested the role of the left inferior frontal gyrus in speech perception and rapid auditory processing, as well as in phonological aspects of reading (Fiez et al., 1995; Fiez & Petersen, 1998; Price, 1998).

Studies that have used functional imaging of this region have found altered patterns of activation among adult dyslexics compared to controls. Shaywitz et al. (1998) recently reported that dyslexics show phonological task hyperactivity in the left inferior gyrus. This enhanced activity in the inferior frontal gyrus may represent a compensatory response to small size or failure of phonological processing mechanisms in more posterior cortical areas. Georgiewa et al. (2002) replicated these results using both fMRI and ERPs among dyslexic and normal children while they silently read words and pronounceable nonwords. The fMRI showed a significant difference in the activation in the left inferior frontal gyrus between the dyslexic and control groups, resulting from a hyperactivation in the dyslexics. Other studies (e.g., Newman & Twieg, 2001; Rumsey et al., 1992) have reported a deficient activation in this area among dyslexics. Variation in these results among studies may reflect different approaches to subject selection and

subtle differences in the cognitive components of the phonological awareness tests that have been utilized (Zeffiro & Eden, 2000).

In this study, the size and asymmetry of the inferior frontal region will be measured. Based on previous studies, it is predicted that a significant correlation will be found between the size of the left inferior frontal gyrus (i.e., Broca's area) and variance on the reading measures in this study. Only one study to-date has explored the relationship between the size of the inferior frontal gyrus in the right hemisphere and the capability of this region to predict specific reading processes (e.g., phonological skill and naming speed). Therefore, this study will also extend the previous findings of Eckert et al. (2003) by exploring whether the size of the inferior frontal gyrus in either hemisphere is significantly related to naming speed or phonological skill.

Planum Temporale

In the early 1980s, Galaburda and his colleagues studied the postmortem brains of eight adults who had experienced reading deficits as children (Galaburda & Kemper, 1979; Galaburda, Sherman, Rosen, Aboitiz, & Geschwind, 1985; Humphreys, Kaufmann, & Galaburda, 1990). These researchers reported a number of differences between the brains of dyslexic readers and nondiagnosed readers. One of the most consistent findings of their studies involved the planum temporale, the transverse surface of the posterior-superior temporal gyrus, a region of cortex believed to be related to language function. In normal individuals, there is a trend of leftward asymmetry (i.e., a left hemisphere larger than the right) of the planum temporale. This leftward asymmetry is present in the fetus (Witelson & Kigar, 1992). The size of the planum temporale in dyslexics, however, was found to be equal between both hemispheres of the brain.

Whereas Galaburda's studies seemed to consistently find reversed or absent asymmetry in dyslexics, more recent studies have failed to confirm these findings. For example, using MRI, Leonard et al. (1993) reported both dyslexics and normal controls demonstrated leftward asymmetry of the planum temporale. Other studies have not reported asymmetry reductions or reversals in dyslexics (Best & Demb, 1999; Rumsey et al., 1997). Among those studies that have reported significant differences between dyslexics and controls, Larsen, Hoien, Lundberg, and Odegaard (1990) was the first to suggest that atypical symmetry of the planum temporale in dyslexia is specifically linked to phonological impairment. They showed that a group of dyslexics in their sample with impaired performance on a nonword reading task had symmetrical planum temporales, whereas those with impaired word recognition did not differ with this respect from the controls. However, in a recent study, Leonard et al. (2001) found no asymmetry differences in this region among a sample of 9 adults with phonological decoding deficits compared to 15 normal controls (matched for sex, handedness, and fluid reasoning). Both groups displayed marked leftward planar asymmetry. Leonard et al. suggest that this region may be more closely associated with comprehension than pure phonological ability. This finding would explain why reversed asymmetry is more often found in studies of children with SLI rather than dyslexia. In addition, the lack of consensus among these imaging studies may be due to poor subject selection, differences in measurement criteria, and inadequate control of confounding variables (Eckert & Leonard, 2000).

In this study, the size and asymmetry of the planum temporale will be measured. Based on previous literature, it is predicted that this region will be significantly correlated

with variance in overall reading achievement, but will not be significantly related to phonological awareness or naming speed.

Heschl's Gyrus

Heschl's gyrus is the location for primary auditory cortex, located in both hemispheres of the brain. Heschl's gyrus receives the ascending auditory projections from the medial geniculate nucleus and relays them to the secondary auditory cortex of the planum temporale and superior temporal gyrus (Leonard et al., 1993). The morphology of Heschl's gyrus varies across individuals; extra gyri are typically found more often in the lateral sections of the temporal lobe (Leonard, Puranik, Kuldau, & Lombardino, 1998). For example, in the left hemisphere, duplicated Heschl's gyri are more often seen in adults with phonological decoding deficits (see Figure 2-4).

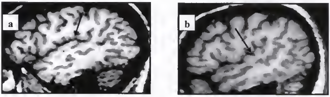


Figure 2-4 MRI Illustrating (a) Single and (b) Double Heschl's Gyri

In two MRI studies investigating brain anomalies, Leonard et al. (1993, 2001) found multiple Heschl's gyri among a mixed sample of children and adults with dyslexia ($n = 9$) and among a sample of adults diagnosed with phonological decoding deficits ($n = 9$). Leonard et al. (1993) hypothesized that, for these individuals, duplicated Heschl's gyri represent misdirected fibers that were intended to connect auditory cortex to the association cortex of the planum temporale. Other studies have investigated the presence of duplicated gyri and performance on processing speed tests, such as IT. In a study

involving college students, Leonard et al. (1998) reported the presence of a duplicated Heschl's gryus in the left hemisphere predicted slow IT in all of the participants ($N = 27$, $r = .60, p < .05$). In a similar study, Grudnik (2001) found a duplicated left Heschl's gyrus predicted slow IT in a sample of normal children who did not experience any language or cognitive deficits ($N = 39$, $r = .64, p < .05$).

In this study, the size of the first, and when present, second Heschl's gyrus will be measured in each hemisphere. Based on previous work, it is predicted that a significant relationship will be found between gyral duplications in this region, particularly in the left hemisphere, and performance on the phonological and processing speed measures in this study. Specifically, an increased surface area in this region will predict slower speeds on these tasks. However, the predicted relationship between the size of Heschl's gyrus and individual differences on the naming speed task is uncertain. This study seeks to address this relationship further.

Corpus Callosum

The largest bundle of white matter fibers that aids in communication between both hemispheres of the brain is the corpus callosum (Lynch, 1997). The corpus callosum consists of four main regions: the rostrum, genu, body, and splenium (see Figure 2-5).

Research suggests disordered interhemispheric communication may play a role in reading problems. Structural variations in cross-sectional areas of the corpus callosum have been reported. In two studies using MRI, Duara et al. (1991) reported a larger splenium and Hynd et al. (1995) found a smaller genu in dyslexics versus control subjects. In a similar study, von Plessen et al. (2002) found a shorter overall shape in the

midbody region of the corpus callosum in a group of 11 year old dyslexic boys versus controls. This region was of particular interest because it contains interhemispheric fibers from primary and secondary auditory cortices (von Plessen et al., 2002). However, there were no significant group differences with respect to overall corpus callosum area, nor any of its subregions. In their study, von Plessen et al. suggest that the overall shape difference found in the reading disabled subjects is consistent with other studies that have reported a strong growth factor in this corpus callosum region during the late childhood years.

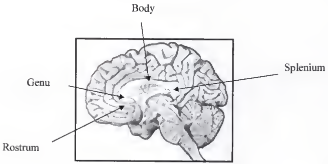


Figure 2-5 Main Regions of the Corpus Callosum

Studies of patients that have experienced lesions of the corpus callosum have been found to perform similarly to normal subjects on tests of interhemispheric transfer time (ITT) of visual motion information. ITT is typically assessed using simple verbal RTs to visually presented information (e.g., letters, words, names) in the opposite hemisphere. For example, in a patient that had experienced a lesion of the posterior two-thirds of the corpus callosum, Clarke et al. (2000) found ITT of visual motion information, as tested by the patient's verbal report of motion perceived with the left visual field, was not

affected by the callosal destruction. In another similar study, Tomaiuolo, Nocentini, Grammaldo, and Caltagirone (2001) reported no differences between a patient with a lesion of the corpus callosum that spared the splenium and rostrum, and normal subjects on a basic visual-motor ITT task.

Although these studies did not report differences in the ITT of patients with corpus callosum lesions, they did find letter and picture naming impairments. For example, in the same subject that performed as well as normal subjects on an ITT task, Clarke et al. (2000) found reading as well as color and picture naming to be impaired when information was presented in the patient's left visual field. In another study, Suzuki et al. (1998) examined corpus callosum disconnection signs in a 14-year old boy with a lesion confined to the posterior part of the splenium. They reported the subject had difficulties reading aloud and copying letters with his right hand when the stimuli were presented in his left visual field. However, he could copy letters presented in his left visual field with his left hand. Therefore, these findings suggest the splenium may be involved in transferring visual information between the hemispheres.

Although studies suggest the corpus callosum aids in interhemispheric communication, research is lacking on the predictive relationship between the corpus callosum and specific components of the reading process. Therefore, the size of the corpus callosum and its subregions will be measured in this study to extend research in this area by exploring whether this region is related to any of the behavioral variables in this study.

Cerebellum

Despite its small size (only 10% of the total weight of the central nervous system), the cerebellum is important in brain function. The cerebellum is composed of a highly convoluted cerebellar cortex and a core of white matter containing cerebellar nuclei. The structure is anchored to the brainstem via the cerebellar peduncles. The cerebellum plays a role in sensory, motor, and higher mental function. (Haines, Mihailoff, & Bloedel, 1997). The cerebellum can be divided vertically into anterior, posterior, and flocculonodular lobes, or horizontally into 2 hemispheres and a vermis (see Figure 2-6).

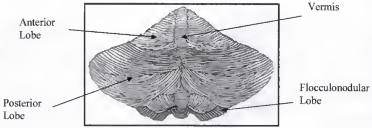


Figure 2-6 Diagram of the Cerebellum

There have been many studies that have linked deficits in the cerebellum to reading impairment. For example, indirect studies of cerebellar function have shown that the cerebellum plays a role in automatization, an important process for fluent reading (Ito, 1984; Nicolson, Fawcett, & Dean, 2001; Stein & Glickstein, 1992). Another indirect study (Ivry & Keele, 1989) found that patients with acute cerebellar damage showed a characteristic dissociation between time estimation and loudness estimation, with a significant deficit only for time estimation. In a more direct study of cerebellar

function, Jenkins, Brooks, Nixon, Frackowiak, and Passingham (1994) studied the relationship between cerebellar activation and automatization in a PET study of normal subjects. In their study, Jenkins et al. had subjects learn a sequence of eight button presses by trial and error using a four-key response board with one key per finger. They found that there was significant activation in the cerebellum both when subjects were executing a previously overlearned (automatic) sequence of presses and also when they were learning a new sequence of presses (compared to when they were at rest). Nicolson et al. (2001) extended Jenkins et al.'s results in a sample of dyslexics and normal controls. Nicolson et al. found, compared to the control subjects, the dyslexics showed significantly less cerebellar activation in the right hemisphere.

There have also been recent studies on cerebellar asymmetry differences investigated by MRI between subjects with reading disabilities and healthy controls. For example, Leonard et al. (2001) found greater leftward asymmetry of the anterior lobe of the cerebellum in a group of adults with phonological decoding deficits ($n = 9$) compared to normal controls. In another similar study, Eckert et al. (2003) reported significantly smaller volumes of the right anterior lobe of the cerebellum among a sample of dyslexic children ($n = 18$) compared to controls ($n = 32$, matched for age). In their study, Eckert et al. also examined the relationship between the volume of the right anterior lobe and performance on oral and written language tests administered to these children. They found a significant correlation between the right anterior lobe and performance on the Elision task (Wagner et al., 1999) ($r = .31, p < .05$) among the dyslexics and controls. In addition, Eckert et al. found a significant correlation between this region and a measure of rapid naming ($r = -.45, p < .05$). Previous studies investigating the cerebellum have

shown that the anterior lobe is associated with spinal and brainstem pathways controlling eye movements, balance, and postural control (Bastian, Mugnaini, & Thach, 1999).

Unlike the findings reported by Leonard et al. (2001), other studies have reported an absence of asymmetry (right > left) in dyslexics versus controls (e.g., Rae et al., 2002). In their study, Rae et al. also found the degree of cerebellar symmetry was correlated with the severity of the subject's phonological deficits (measured using nonword reading). It was found that those subjects with more symmetric cerebella made more errors on a response word reading measure of phonological decoding ability. Rae et al. suggest that there is a relationship of cerebellar asymmetry to phonological decoding ability and motor skills due to alterations in the neurological organization of the cerebellum.

In the only other fMRI study of the RAN task that could be located, Eden et al. (2000) reported activity in the right lateral cerebellum was rated to performance on the RAN task. However, these results are preliminary and further work exploring the possible role of the cerebellum during timed automatized naming tasks is needed. Therefore, the cerebellum will be measured in this study to test this predicted relationship.

Magnetic Resonance Imaging in Children

The purpose of this study is to explore the aforementioned brain structures using MRI in a group of normal school-age children. Although fMRI is commonly used today to infer brain function, few studies have used fMRI with a sample of children (e.g., Casey et al., 1995; for a review see, Casey, Giedd, & Thomas, 2000). The advantage of using MRI is that it allows researchers to investigate individual differences in the cortical

variation (i.e., size and morphology) of distinct areas in the brain. In particular, studies involving MRI with normal children can provide valuable information about cerebral cortex characteristics in the normal population. This is important because these findings can lead to neurobiological based hypotheses concerning the neuroanatomy involved in different aspects of the reading process, such as naming speed. These findings can also be useful for future research involving reading disabled children. The information obtained from this study may provide a foundation for the development of better techniques for early identification and treatment of children who are at high risk of experiencing later reading failure.

Sampling Issues

In any neuroanatomical investigation, especially those involving children, there are several important considerations that may affect brain-behavior relationships. In particular, it is important to examine the effects of sex, age, and handedness and their relation to individual differences in brain structure.

Since the time of Broca (1861), it has not been disputed that an absolute difference in brain size exists between men and women. Imaging studies consistently point to sex differences in overall brain size with adult males having, on average, a 10% greater volume than females. In a study investigating brain development in children, Reiss, Abrams, Singer, Ross, and Denckla (1996) extended that finding to a large group of children as young as five years old. This result strongly suggested the presence of early sex-associated differences in cerebral development and organization. At the cytoarchitectonic level, Witelson, Glezer, and Kigar (1995) found the neuronal density of the granular layers of the cerebral cortex to be significantly higher in females, than in

males, especially in the planum temporale. This is one potential explanation for sex differences in brain size.

MRI investigations have shown a curvilinear pattern of growth and change, with an overall decrease in brain volume following the late teens. Post-mortem studies show that the human brain attains adult weight by early childhood, usually around ages 5-10 years (Lemire, Loeser, Leech, & Alvord, 1975). Reiss et al. (1996) replicated that finding in a sample of children ages 5 to 17 years. According to Rushton and Ankney (1996), the average mass of the brain increases from 397 g at birth to 1,180 g at 6 years. Since this study involves school-age children, age is considered an important factor and will be investigated in this study.

Another potential confound is handedness. Seventy percent of the population are strongly right handed (dextral), while only 4% are strongly left-handed (Annett, 1998; Annett & Manning, 1990; McManus & Bryden, 1993). In addition to language lateralization, structural variables may also be associated with handedness. For example, normal individuals that are not right handed (i.e., adextral) are more likely to exhibit reduced or reversed asymmetry of the planum temporale and the cerebral hemispheres (Steinmetz, Volkmann, Jancke, & Freund, 1991; Witelson & Kigar, 1992). Since these areas in the brain, among others, will be measured in this study, the potential effects of handedness will be considered.

## Summary and Conclusions

The relationship of phonological skill to reading growth and reading disability has been well documented (Lyon, 1995; Share, 1995; Stanovich, 1988; Stanovich & Siegel, 1994; Torgesen et al., 1994; Torgesen et al., 1997; Vellutino & Scanlon, 1987; Wagner &

Torgesen, 1987). However, growing evidence has implicated a second class of factors, associated with the rapid naming of familiar stimuli, as an independent source of reading problems (Cornwall, 1992; Cutting et al., 1998; Manis et al., 2000; Wagner et al., 1993; Wagner et al., 1994). Rapid visual naming represents a demanding array of attentional, perceptual, conceptual, memory, lexical, and articulatory processes (Wolf & Bowers, 1999). Although research has explored some of these component processes and naming, questions concerning the relation between naming speed and reading remain.

In addition to investigating the relationship between specific behavioral variables and reading achievement, it might also be useful to explore the relationship between neuroanatomy and these predictors. By localizing and measuring the various brain regions thought to subserve language, the findings in this study may yield important insight into how reading is accomplished and what structures are involved in the various components of the process, such as naming speed.

The goal of this study is to examine the relationship between naming speed and reading achievement in a sample of normal children. The specific research questions that will be addressed are: (a) is naming speed strongly associated with reading achievement, independent of phonological awareness; (b) is naming speed associated with "nonphonological" predictors of reading, such as cognitive ability and processing speed, and if so, how does this affect naming speed's relationship with reading achievement; and (c) what is the relationship between neuroanatomy and specific predictors of reading, such as naming speed? The findings from this study will provide a foundation for future research investigating the behavioral and neuroanatomical predictors of reading achievement.

# CHAPTER 3
# METHOD

## Participants

Participants in this study were 33 girls and 24 boys between the ages of 7 and 11 years ($M = 9.04$, $SD = .99$). Participants for this study were selected from an archival data set that was collected during a longitudinal study that began in 1996. At that time, letters explaining the study were sent to all the parents of children in public schools within Alachua County. When potential subjects were identified, children with sensory impairments and neurological or psychiatric diagnoses were excluded. Services received and clinical histories were determined though interviews with at least one parent or guardian. All testing was performed at the University of Florida McKnight Brain Institute. All participants and their parents read and signed a Human Subjects consent form approved by the University of Florida Institutional Review Board prior to the onset of the study. The data collected for the present study represent a subset of tests that were administered to these participants throughout the course of the longitudinal study.

## Tests Administered

### Handedness

One test of manual preference and one test of hand skill were performed. Hand preference was measured with a performance inventory modified from the Edinburgh battery (Briggs & Nebes, 1974). The peg-moving test (Annett & Manning, 1990) was used to measure hand skill. Participants were classified as right handed if they wrote

with their right hand and obtained a quantitative score on the performance inventory greater than .75. All others were classified as non-right. Thirty-seven of the 57 participants were right-handed.

Socioeconomic Status

Socioeconomic status was calculated using the Hollingshead four factor index of social status (Hollingshead, 1975). Information on parent education and occupation was obtained and rated on a scale of one to seven and one to nine, respectively. The scaled scores were then multiplied by a weight of five and three, respectively. If the child came from a single-parent household or a single-earned household, the score was calculated using the working parent's occupation. However, if both parents worked, the scores were added together and then averaged. Computed scores ranged from a high of 64.5 to a low of 19.5 in this study.

Cognitive Ability

Participants were administered the standard cognitive battery of the Woodcock Johnson-Tests of Cognitive Ability-Revised (WJ-Cog) (Woodcock & Johnson, 1989a). The WJ-Cog is a comprehensive test battery available for the cognitive assessment of children and adults (ages 2 to 90+ years). The WJ-Cog closely models the major concepts of the Horn-Cattell $G_f$-$G_c$ theory of fluid and crystallized intelligence. The WJ-Cog battery consists of seven standard and 14 supplemental tests. The broad abilities that were measured in this study were assessed with the following standard WJ-Cog tests: (a) Long Term Retrieval ($G_{lr}$): Memory for Names; (b) Short Term Memory ($G_{sm}$): Memory for Sentences; (c) Processing Speed ($G_s$): Visual Matching; (d) Auditory Processing ($G_a$):

Incomplete Words; (e) Visual Processing ($G_v$): Visual Closure; (f) Comprehension-Knowledge ($G_c$): Picture Vocabulary; and (g) Fluid Reasoning ($G_f$): Analysis-Synthesis.

Internal consistency reliabilities ($r_{xx}$) and standard errors of measurement (SEMs) have been calculated for these seven tests and range from .63 to .91 and 3.0 to 5.9, respectively, in the 9 year-old age group. Additionally, because each of these tests is intended to measure a different aspect of cognitive ability, intercorrelations between them are low. Construct validity measures for the nine year-old age group range from .18 to .33 (Woodcock & Mather, 1990a).

The broad cognitive ability (BCA) score of the WJ-Cog is based on a differentially weighted composite of the cognitive tests. This composite score was used in this study as a broad-based measure of intellectual ability. The BCA score has a median reliability of .93 in the kindergarten to grade 12 range (Woodcock & Mather, 1990a).

Phonological Awareness

Participants were given two measures of phonological awareness, the Elision task (Torgesen, 1993) and the Lindamood Auditory Conceptualization test (LAC). The Elision task is presented in the form of a word game where the child verbally manipulates the sounds. The LAC uses blocks to represent sounds and the participant manipulates the blocks to represent speech sounds provided by the examiner. A detailed description of these tests can be found in the following paragraphs.

The Elision task that was used in this study is nearly identical to a recently published battery of phonological processing tests by Wagner et al. (1999). The test contains 25 items and requires participants to manipulate word segments and phonemes

by omitting and deleting them to make new words. Although reliability information for the current task is not available, the test-retest reliability coefficient for the recently published (Wagner et al., 1999) Elision task for children between five and seven years old is high ($r = .88$).

The LAC, an individually administered test, is designed to evaluate children's ability to discriminate speech sounds as well as to perceive the number and order of sounds within a spoken pattern. The test is intended to be used with children in kindergarten through grade 12 to aid in the identification of auditory perceptual deficiencies. The standardization sample consisted of 660 kindergarten through grade 12 boys and girls from a large heterogeneous California school district. Alternate-form reliability is high ($r = .96$). Within-grade reliability is not available. Correlations between the combined reading and spelling subtests of the Wide Range Achievement Test (Jastak, Bijou, & Jastak, 1978) and the LAC range from .66 to .81 with a median of .75 (Sattler, 1992). After 6th grade, participants are expected to score between 99 and 100.

Serial Naming Speed

Participants were administered the Rapid Automatized Naming (RAN) task, a measure of naming speed (Denckla & Rudel, 1974, 1976a, 1976b). The ability to rapidly name colors, numbers, and letters has been associated with reading development (Badian, 1997; Blachman, 1984; Bowers, 1995; Denckla & Rudel, 1976b; Wagner et al., 1994; Wolf et al., 1986; Wolf et al., 2000).

Participants were presented a set of colors, letters (uppercase), and numbers on laminated 8 by 10 in. cards and told to name the items as quickly as they can. Prior to the

timed trial, participants were tested to determine whether they knew the colors, letters, and numbers being presented. If they did not know the colors, letters, or numbers presented on the card, the trial for the unknown items was omitted. The amount of time required for each type of stimulus was recorded.

Reliability information for the particular items that were administered is not available. However, the recently published battery of tests by Wagner et al. (1999) includes a test nearly identical to that of the RAN used in the current study. The test-retest reliability coefficients for the RAN in their battery for colors ($r = .78$) and letters ($r = .97$) are high.

Reading Achievement

Participants were administered three tests from the Woodcock-Johnson Tests of Achievement-Revised (WJ-Ach), to assess reading skills and performance (Woodcock & Johnson, 1989b). The WJ-Ach is a wide-range, comprehensive test battery available for measuring achievement in various subjects, namely reading, mathematics, written language, science, social studies, and humanities (ages 2 to 90+ years). The WJ-Ach standard battery consists of nine standard and nine supplementary tests. The areas of achievement that were measured in this study were assessed with the following standard and supplementary tests: (a) Reading Identification Skills: Letter-Word Identification; (b) Comprehension and Vocabulary Skills: Passage Comprehension; and (c) Phonic and Structural Analysis Skills: Word Attack.

In addition to yielding scores for each of the individual tests, administration of these three tests provides scores for two skill clusters. The Broad Reading Skills cluster is a combination of the Letter-Word Identification and Passage Comprehension tests and

provides a broad measure of reading achievement. Its median reliability is .94 in the kindergarten to grade 12 range. The Basic Reading Skills cluster is a combination of Letter-Word Identification and Word Attack and provides a measure of basic reading skills that includes both sight vocabulary and the ability to apply phonic and structural analysis skills.

Internal consistency reliability coefficients ($r_{xx}$) and standard errors of measurement (SEMs) have been calculated for these tests and clusters and range from .88 to .96 and 3.4 to 5.8, respectively in the nine year-old age group. Intercorrelations between each of these tests and clusters range from .64 to .91 for the nine year-old age group (Woodcock & Mather, 1990b).

Cognitive Processing Speed

Processing speed was assessed by performance on the following elementary cognitive tasks (ECTs): Simple RT, Choice RT, Odd-Man-Out RT, and a Visual IT task.

Visual Inspection Time. The IT apparatus consisted of a 20 by 14 in. gray metal box with a black front. On the front side, there were two vertical columns of multiple segment red bar light emitting diodes (LEDs) 6 in. long, 1 1/2 in. apart. Two 4 3/4 by 2 1/2 in. pushbutton boxes were connected to the apparatus (one is held in each of the participant's hands). A pushbutton (1/4 in. in diameter) was located in the center of each hand-held box. The IT apparatus was interfaced with a personal computer.

For the IT paradigm, a single trial consisted of: (a) an auditory warning signal was presented (a beep of 1 s duration); (b) following a random interval of 1 to 3 s, both of the parallel columns of LEDs were illuminated, one of which was 30% longer than the other (see Figure 3-1); (c) almost immediately afterwards, both lines became equal (backward

masking) to prevent further processing; and (d) the participant indicated which line (right or left) was longer by depressing the corresponding pushbutton (right or left). The resulting IT referred to the minimum exposure duration necessary for the participant to reliably discriminate between the two lines.

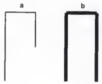


Figure 3-1 The Inspection Time (a) Testing Figure and (b) Masking Figure

The lines were displayed for 15 to 400 ms. The exact number of trials and the specific exposure times of the stimuli for each trial were determined by the BRAT algorithm, an adaptive staircase procedure, in which testing begins with a long exposure duration, and subsequent exposures are either lengthened or shortened due to the accuracy of the participant's responses (Barrett et al., 1998). The BRAT algorithm consisted of three phases. In Phase I, a quick estimate of IT was determined by starting well above the participant's IT (e.g., 500 ms) and decreased in relatively large increments (10 ms steps after the stimulus exposure duration was under 100 ms) until at least 90% accuracy had been attained in the last 10 trials. In Phase II, the initial estimate was further refined by first overshooting the Phase I estimate of IT by 30 ms and then slowly increasing (in 6 ms steps) the stimulus duration until at least a 90% response accuracy was obtained in the last 10 trials. Finally, in Phase III, the participant's IT was determined by initially overshooting the IT estimate provided in Phase II by 20 ms and

then increasing the stimulus duration (in 2 ms steps) until the participant made nine consecutive correct responses. The IT estimate provided at the end of Phase III was considered the participant's resolved IT. The IT task typically required less than 100 trials and 10 to 15 minutes to administer. A participant's failure to resolve an IT within the 15 minute time limit was referred to as "timing out."

Previous work reports a 30% timing out rate when using the IT task with a group of children (Grudnik, 2001). In that study, Grudnik combined the Phase II estimate from the timed out group with the resolved IT estimate of the remaining participants. She reported a .98 correlation ($p < .05$) between these two scores. In the present study, 15 participants timed-out during the task. Therefore, the resolved IT times of the remaining participants ($N = 41$) were combined with the Phase II times of these participants to increase the overall sample estimate ($N = 57$).

Previous studies have reported substantial correlations between IT and measures of IQ (for a review see Grudnik & Kranzler, 2001). In two overlapping meta-analyses (Grudnik & Kranzler, 2001; Kranzler & Jensen, 1989) of the relationship between IT and IQ, both reported the best estimate of the relationship to be around -.50. For children, the estimate is slightly lower, around -.40.

Reaction Time Paradigm. The same apparatus was used for all RT paradigms in the study, which is very similar to the original Jensen apparatus (Jensen & Monro, 1979). The apparatus consisted of a 13 by 17 in. console tilted at a 30 degree angle. The "home button," a blue pushbutton 1 in. in diameter, was located at the lower center of the panel. The response buttons were located in an array of 8 yellow pushbuttons, 1/2 in. in

diameter. They were arranged equidistant from the home button in a semicircle with a 6 in. radius (see Figure 3-2).

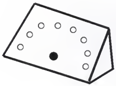

Figure 3-2 The Response Console of the Reaction Time Apparatus

For the Simple and Choice RT paradigms, a single trial consisted of: (a) the participant depressed the home button; (b) an auditory warning signal (i.e., a beep of 1 s duration) was presented; (c) one of the pushbuttons was illuminated, following a 1 to 4 s interval; (d) the participant, as quickly as possible, removed his or her finger from the home button and depressed the illuminated pushbutton. In the Simple RT task, the same pushbutton lit up, for the Choice RT any one of the eight pushbuttons may of lit up in a given trial.

The apparatus allowed the separate measure of both RT and Movement Time (MT) in ms by electronic timers. RT is the amount of time it took the participant to lift his or her finger off the home button after one of the pushbuttons had lit up. MT referred to the interval between lifting his or her finger off the home button and depressing the illuminated pushbutton. There are 20 total trials for both Simple and Choice RT and each test took about 5 minutes to administer.

The apparatus and procedure for the Odd-Man-Out task was similar to Simple and Choice RT, except that instead of one pushbutton going on, three pushbuttons were

illuminated simultaneously. Two of these pushbuttons were closer to each other than the third (see Figure 3-3). The participant must depress the pushbutton that is further away from the other two. RT and MT were also recorded for this task in ms by electronic timers. There were 20 trials for this test and it took about 5 minutes to administer.

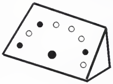

Figure 3-3 The Odd-Man-Out Task of Reaction Time

Previous studies have reported correlations ranging from -.20 to -.40 between RT and measures of IQ for adults and children (Kranzler, 1994; Rijsdijk et al., 1998; Vernon, 1993).

## Neuroanatomical Assessment

### MRI Scan Protocol and Image Preprocessing

Each participant received a volumetric MRI scan in a 1.5 Siemens Magnetom scanner. Two scan sequences were performed using a quadrature head coil: (a) a gradient echo volumetric acquisition "Turboflash" MP Rage sequence ($T_R$ = 10 ms, $T_E$ = 4 ms, $F_A$ = $10^{\circ}$, 1 acquisition, 25 cm field of view, matrix = 130 x 256) that was reconstructed into a gapless series of 128, 1.25 mm thick images in the sagittal plane, and (b) a traditional axial scan of 5 mm $T_2$ and spin density weighted images separated by 2.5 mm gaps (time = 8 min). The images were electronically transferred to the neuroimaging lab at the University of Florida and assigned a random blind number. Programs written in PV-

Wave (a programming language designed for handling large arrays from Visual Numerics, Inc., Boulder, CO) processed the images and place them into a single file. Films were sent to a neuroradiologist to examine for clinically significant findings. The Talairach proportional grid method (Talairach & Tournoux, 1988) was used to insure that comparable regions were examined in each brain. This system standardizes positions by relating them to an atlas brain where the horizontal plane intersects the anterior and posterior commissure. After the degree of head tilt in each of the three orthogonal planes was determined, the scans were reformatted into a final set of sagittal and coronal scans in the Talairach planes. The size of the brain was not altered during reformatting; the coordinates were simply used to designate proportional locations. Two raters blind to subject characteristics made each measurement and differences greater than 15% were resolved by discussion and remeasurement.

The volume of each cerebral hemisphere (BV) was measured by tracing the area enclosed by the dura on every fourth sagittal image, and summing the averages of adjacent areas after multiplying by the width of the inter image gap. The midsection was traced twice and half the slab volume added to each hemisphere. This measure included intra sulcal cerebrospinal fluid and thus reflected original cerebral capacity before the onset of age-related cortical loss. Inter-rater reliability of this measure was >.90 (intra-class correlation). The volumes of the two hemispheres (Left BV and Right BV) were added together to estimate total cerebral volume (Total BV). The coefficient of asymmetry (Asym BV) of the cerebral hemispheres was calculated by dividing the right and left differences by the average volume of the two hemispheres. Rightward asymmetry is positive.

The following section describes the methods that were used to measure the specific neuroanatomical regions of interest to the current study.

Inferior Frontal Gyrus

The pars triangularis (PT) and pars opercularis comprise Broca's area and are located on the inferior frontal gyrus. The inferior frontal gyrus is divided into these constituent parts by the ascending rami of the Sylvian fissure. Using a strict anatomical definition, the PT extends superiorly to the inferior frontal sulcus, inferiorly to the anterior horizontal ramus, and caudally to the anterior ascending ramus. The pars opercularis is located adjacent to the PT, but in a more caudal location. Measurements were limited to the surface area of the convolutions that form the inferior and caudal boundary of the PT. The PT was measured from 39 to 49 Talairach mm. The PT was measured by tracing the surface formed by the anterior ascending ramus and the anterior horizontal ramus of the sylvian fissure. These are the two major branches of the Sylvian fissure and thus easily identified. The surface was traced from the tip of the anterior ascending ramus, down to the Sylvian fissure and thus following the anterior horizontal ramus to the end. This region of interest was measured in the left and right hemispheres (Left PT and Right PT) of each subject. Inter-rater reliability of this measure was >.85.

Planum Temporale

The surface area of the temporal bank of the planum (Planum) was measured between the posterior boundary of Heschl's gyrus, and the termination of the sylvian fissure, which in many cases is marked by a small elevation in the planum and a bifurcation into a descending ramus and the posterior ascending ramus, commonly referred to as the planum parietale (Parietale). The small posterior descending ramus

which originates from a bifurcation was not included in the measure. In cases where the Parietale originates proximally to the termination of the sylvian fissure (inverted formation) (Ide, Rodriguez, Zaidel, & Aboitiz, 1996), the large extent of sylvian fissure posterior to the Parietale was included in the Planum measurement. The Parietale was measured from the bifurcation to its dorsal termination. In the small number of cases where no elevation of bifurcation marks the origin of the Parietale, the "knife cut" method was used (Witelson & Kigar, 1992). In cases where the sylvian fissure merged with the superior temporal sulcus or other occipitoparietal sulci, the Parietale and Planum measurements was terminated at the point of the merge. An index of surface area was calculated by averaging the length measured between Talairach $x = 46$ and $x = 56$ as reported previously (Foundas, Leonard, & Heilman, 1995; Leonard et al., 1993; Leonard et al., 1996). Inter-rater reliability of this measure was >.90. On the average, planar asymmetry (Planar Asym) is leftward and parietale asymmetry (Parietale Asym) is rightward.

Heschl's Gyri

The surface area of the first Heschl's gyrus (H1) and, when present, a second (H2) gyrus (Leonard et al., 1998) was traced between their limiting sulci on consecutive sagittal images from their medial origin at $x = 34$ and laterally to $x = 48$. In cases where there is no obvious H2, tracing was continued to the first angle in the temporal plane. Inter-rater reliability for this method was >.81.

Corpus Callosum

The corpus callosum (CC) was divided into five subregions using a straight line method. These callosal subregions were based on findings from anatomical studies

delineating the anterior-posterior topographical distribution of cortical neurons through the CC in humans (DeLacoste, Kirkpatrick, & Ross, 1985) and in previous studies investigating individual differences in human callosal morphology (Witelson, 1989). In the straight line method, the perimeter of CC is traced. Then, vertical lines are drawn tangent to the anterior and posterior extremes of the CC. The horizontal straight line distance between the anterior and posterior end points was calculated and the CC was divided into five subregions by constructing equidistant lines perpendicular to the horizontal line (Rostrum, Genu, Body, Isthmus, and Splenium). The area of each subregion was then computed. The inter-rater reliability of this method was >.84.

Cerebellum

The anterior lobe of the cerebellum (Ant Lobe) was measured in sagittal images. Every 1 mm thick section on which the primary fissure can be seen was outlined and the areas added to calculate the volume in each hemisphere. As the primary fissure becomes indistinct laterally (Larsell & Jansen, 1972), the lateral boundary of the Ant Lobe was defined as the image on which the superior cerebellar vessels disappeared. Inter-rater reliability for this method was >.90. The coefficient of asymmetry (Asym Ant Lobe) was calculated by dividing the left and right difference by the volume of the two hemispheres (Left Ant Lobe and Right Ant Lobe). Leftward asymmetry is positive.

## Procedure

Participants in this study were tested by trained graduate students in the School Psychology Program at the University of Florida. Testing took place in three sessions, each lasting approximately 1 to 2 hours. The psychometric tests and ECTs were administered in two sessions, with a third session, referred to as "scan day," designed

especially for the MRI and handedness measure acquisition. On the sessions for which the ECTs were administered, they were done first, lasting about 20-25 minutes, with the psychometric tests following, lasting no more than one hour. For each of the ECTs, children were instructed to perform as fast as they could without making errors. Children were also given as many practice trials on the ECTs as needed until they clearly understood the task.

## Statistical Analyses

All variables were entered into Microsoft Excel spreadsheets and analyzed with SPSS Base 11.0, a statistical software package for the personal computer. Descriptive statistics were calculated for all demographic, behavioral, and neuroanatomical variables. For each of the behavioral measures, a scatter plot was printed and analyzed to identify outliers; therefore, the sample sizes for some of these tasks may be lower than others. Pearson product-moment correlations and simultaneous multiple regression analyses were used to determine relationships among the variables. Hypothesis testing for each research question will be discussed in detail in the following section.

### Hypothesis Testing

Recall that the research questions are as follows: (a) is naming speed strongly associated with reading achievement, independent of phonological awareness; (b) is naming speed associated with "nonphonological" predictors of reading, such as cognitive ability and processing speed, and if so, how does this affect naming speed's relationship with reading achievement; and (c) what is the relationship between neuroanatomy and specific predictors of reading, such as naming speed?

Hypothesis testing associated with Question 1 will be supported if naming speed is significantly related to reading achievement. More specifically, hypothesis testing will be supported if naming speed accounts for a sizable amount of variance in reading while controlling for phonological awareness. This hypothesis will be investigated through the use of correlation analyses and simultaneous multiple regression analyses. Table 3-1 displays a complete list of all the independent and dependent variables that will be used to address Question 1. Relationships between these variables and age, sex, and SES will also be investigated.

Table 3-1

Independent and Dependent Variables Associated with Question 1

| Independent Variables | Dependent Variables |
|---|---|
| Elision | Letter-Word Identification |
| LAC | Passage Comprehension |
| RAN Colors | Word Attack |
| RAN Numbers | Broad Reading Skills |
| RAN Letters | Basic Reading Skills |

Hypothesis testing associated with Question 2 will be supported if naming speed is significantly related to other nonphonological variables examined in the study, including cognitive ability and measures of processing speed. More specifically, hypothesis testing will be supported if naming speed accounts for a sizable amount of variance in reading achievement with the inclusion of these variables. This hypothesis will be investigated through the use of correlation analyses and simultaneous multiple

regression analyses. Table 3-2 displays a complete list of the independent and dependent variables that will be used to address Question 2. Relationships between these variables and age, sex, handedness, and SES will also be investigated.

Table 3-2

Independent and Dependent Variables Associated with Question 2

| Independent Variables | Dependent Variables |
|---|---|
| Elision | Letter-Word Identification |
| LAC | Passage Comprehension |
| Cognitive Ability | Word Attack |
| Processing Speed (IT, RT) | Broad Reading Skills |
| RAN Colors | Basic Reading Skills |
| RAN Numbers | |
| RAN Letters | |

Hypothesis testing associated with Question 3 will be supported if variance in brain structure is significantly related to the specific aspects of reading investigated in this study. This hypothesis will be investigated through the use of correlation analyses and simultaneous multiple regression analyses. Table 3-3 displays a simplified list of the independent and dependent variables that will be used to address Question 3. The left and right hemisphere and asymmetry measures associated with each brain structure will also be included. Relationships between the independent variables and age, sex, handedness, and SES will also be investigated.

Table 3-3

Independent and Dependent Variables Associated with Question 3

| Independent Variables | Dependent Variables |
| --- | --- |
| Total Brain Volume | Naming Speed |
| Inferior Frontal Gyrus | Phonological Awareness |
| Planum Temporale | Reading Achievement |
| Heschl's Gyrus | Cognitive Ability |
| Corpus Callosum | Processing Speed |
| Cerebellum | |

# CHAPTER 4
# RESULTS

The results of this study are presented in four sections. The first section presents results of the descriptive statistics for all of the variables investigated in this study. Included in this section are results of $t$ tests and correlation analyses used to investigate significant relationships with age, sex, handedness, and SES. The next three sections present results for each of the main hypotheses of the study. The implications of these findings are discussed in Chapter 5.

## Descriptive Statistics

### Psychometric Variables

Tables 4-1 to 4-4 display descriptive statistics for the psychometric variables measured in the study. The scores for BCA, Letter-Word ID, Passage Comp, Word Attack, Broad Reading, and Basic Reading are standard scores ($M = 100$, $SD = 15$). As can be seen from Table 4-1, the mean scores for these measures fall in the average to high average range when compared to same-age peers. The sample is slightly restricted in range.

The mean scores reported for the Elision and LAC tests are raw scores. A maximum of 25 points is possible for the Elision test, and 100 for the LAC test. The mean scores reported for the RAN Colors, RAN Numbers, and RAN Letters tests are mean response time (sec). Low scores on these tasks represent quick response times.

Table 4-1

Descriptive Statistics for the Psychometric Tests

| Psychometric Test | *N* | *M* | *SD* | Range |
|---|---|---|---|---|
| BCA[a] | 55 | 106.82 | 11.41 | 83-128 |
| Elision[b] | 57 | 18.95 | 4.29 | 10-25 |
| LAC[c] | 57 | 69.37 | 18.89 | 23-100 |
| RAN Colors[d] | 56 | 42.72 | 7.99 | 30-60 |
| RAN Numbers[d] | 52 | 29.28 | 6.65 | 18-51 |
| RAN Letters[d] | 52 | 29.31 | 6.97 | 18-55 |
| Letter-Word ID[a] | 56 | 110.32 | 14.89 | 86-146 |
| Passage Comp[a] | 56 | 114.11 | 13.20 | 89-143 |
| Word Attack[a] | 57 | 109.25 | 14.97 | 81-146 |
| Broad Reading[a] | 56 | 112.07 | 12.93 | 88-144 |
| Basic Reading[a] | 56 | 109.54 | 14.95 | 86-143 |

Note: [a]$M = 100$, $SD = 15$; [b]Maximum score = 25; [c]Maximum score = 100; [d]Time in seconds

Table 4-2 presents results of *t* tests used to examine mean differences by sex on all of the psychometric tests. It is important to note that the Bonferroni method was used to control for Type I error on all of the *t* tests used in this study. As can be seen in this table, no mean differences between males and females were found.

Table 4-3 presents correlations between SES and psychometric test performance. As can be seen from the table, SES did not significantly correlate with performance on any of the measures.

Table 4-2

Descriptive Statistics by Sex Across Psychometric Test Performance

| Psychometric Test | | *N* | *M* | *SD* | *t* | *p* |
|---|---|---|---|---|---|---|
| BCA | M | 24 | 106.42 | 13.29 | -.22 | .83 |
| | F | 31 | 107.13 | 9.93 | | |
| Elision | M | 24 | 18.08 | 5.03 | -1.24 | .22 |
| | F | 33 | 19.58 | 3.61 | | |
| LAC | M | 24 | 70.67 | 20.84 | .44 | .66 |
| | F | 33 | 68.42 | 17.61 | | |
| RAN Colors | M | 23 | 42.30 | 6.95 | -.33 | .75 |
| | F | 33 | 43.02 | 8.74 | | |
| RAN Numbers | M | 22 | 28.70 | 5.36 | -.53 | .60 |
| | F | 30 | 29.69 | 7.52 | | |
| RAN Letters | M | 22 | 29.13 | 5.16 | -.16 | .88 |
| | F | 30 | 29.44 | 8.14 | | |
| Letter-Word ID | M | 24 | 107.96 | 15.86 | -1.03 | .31 |
| | F | 32 | 112.09 | 14.11 | | |
| Passage Comp | M | 24 | 111.50 | 13.14 | -1.29 | .20 |
| | F | 32 | 116.06 | 13.11 | | |
| Word Attack | M | 24 | 108.17 | 17.23 | -.46 | .65 |
| | F | 33 | 110.03 | 13.31 | | |
| Broad Reading | M | 24 | 109.50 | 13.87 | -1.30 | .20 |
| | F | 32 | 114.00 | 12.04 | | |
| Basic Reading | M | 24 | 108.08 | 16.95 | -.61 | .55 |
| | F | 32 | 110.63 | 13.43 | | |

Table 4-4 presents correlations between age and performance on the psychometric tests. As can be seen in this table, age statistically significantly correlated with scores on

the LAC, RAN Colors, and RAN Numbers tests. Based on these results, age was controlled for in later analyses in this study.

Table 4-3

Pearson Product-Moment Correlations Between SES and Psychometric Test Performance

| Psychometric Test[a] | *r* | *p* |
|---|---|---|
| BCA | .08 | .57 |
| Elision | -.15 | .28 |
| LAC | .05 | .73 |
| RAN Colors | -.04 | .75 |
| RAN Numbers | -.01 | .95 |
| RAN Letters | .24 | .09 |
| Letter-Word ID | -.08 | .58 |
| Passage Comp | -.02 | .91 |
| Word Attack | -.07 | .60 |
| Broad Reading | -.07 | .63 |
| Basic Reading | -.10 | .47 |

Note: [a]Refer to Table 4-1 for *M*s and *SD*s

Table 4-4

Pearson Product-Moment Correlations Between Age (in months) and Psychometric Test Performance

| Psychometric Test[a] | $r$ | $p$ |
|---|---|---|
| BCA | .10 | .45 |
| Elision | .22 | .10 |
| LAC | .34* | .01 |
| RAN Colors | -.35* | .01 |
| RAN Numbers | -.29* | .04 |
| RAN Letters | -.24 | .09 |
| Letter-Word ID | -.01 | .92 |
| Passage Comp | -.17 | .20 |
| Word Attack | -.13 | .32 |
| Broad Reading | -.03 | .83 |
| Basic Reading | -.01 | .94 |

Note: [a]Refer to Table 4-1 for *M*s and *SD*s; $^{*}p < .05$

Elementary Cognitive Tasks

Tables 4-5 to 4-9 display descriptive statistics for the elementary cognitive tasks (ECTs) used in this study. For the IT task, it should be noted that 14 children were not able to resolve an IT. The computer "timed out" before an IT was registered for these participants. Therefore, the Phase II times of the "timed out" group were included with the ITs of the "resolved" group to increase the overall sample size. Previous studies (e.g., Grudnik, 2001) report a .98 correlation ($p < .05$) between these two scores. For the RT

task, three experimental variables were measured for each participant: RT, MT (movement time) and errors (mean number of errors during each RT task).

The means and SDs reported in this study were compared to the results of other studies using these same tasks (see Freason & Eysenck, 1986; Grudnik, 2001; Jensen, 1987; Kranzler & Jensen, 1991). It is important to note that the means and SDs in this study are somewhat higher than those typically reported; however, they are comparable to the results of other studies with similarly aged children.

As can be seen from Table 4-5, the mean RTs and MTs increase as complexity of the RT task increases from Simple RT to Odd-Man-Out (OMO) RT. The mean RTs for the Simple, Choice, and OMO tasks are as follows: 356.3, 442.4, and 844.5, respectively. Significant differences were found between the mean RTs of the Simple and Choice tasks ($t = -9.48$, $df = 48$, $p < .05$) and between the Choice and OMO tasks ($t = -12.89$, $df = 51$, $p < .05$). A statistically significant difference was also found between the mean MTs of the Choice and OMO tasks ($t = -2.83$, $df = 49$, $p < .05$). In addition, for all three tasks, the MTs were significantly faster than their corresponding RTs (all *p*s < .05).

As can also be seen in the table, the mean number of errors for each task was also calculated. The expected pattern, with increasing numbers of errors made for more complex tasks, was not found between Simple and Choice RT, nor were they significantly different. The expected pattern did hold between the Choice and OMO tasks. The number of errors made on the OMO task was significantly greater than on the Choice task ($t = -8.05$, $df = 50$, $p < .05$).

Table 4-5

Descriptive Statistics (in ms) for the Elementary Cognitive Tasks

| Elementary Cognitive Task | *N* | *M* | *SD* |
|---|---|---|---|
| Visual IT | 53[a] | 109.7 | 34.7 |
| Simple RT | 50 | 356.3 | 54.9 |
| Simple MT | 48 | 310.4 | 95.9 |
| Simple Errors | 52 | 2.5 | 3.2 |
| Choice RT | 54 | 442.4 | 84.4 |
| Choice MT | 51 | 322.9 | 74.0 |
| Choice Errors | 53 | 2.0 | 3.0 |
| OMO RT | 53 | 844.5 | 262.9 |
| OMO MT | 53 | 360.7 | 82.0 |
| OMO Errors | 52 | 10.6 | 9.2 |

Note: [a]Includes Phase II Times for Timed-Out Group ($n = 14$)

Tables 4-6 to 4-9 present results of $t$ tests and correlations used to examine mean differences by age, sex, handedness, and SES on all of the ECTs. As can be seen from Tables 4-6 and 4-7, no significant sex or handedness differences were found for any of the tasks.

Table 4-6

Descriptive Statistics (in ms) by Sex
Across Elementary Cognitive Task Performance

| Elementary Cognitive Task | | *N* | *M* | *SD* | *t* | *p* |
|---|---|---|---|---|---|---|
| Visual IT | M | 22 | 102.9 | 33.4 | -1.20 | .24 |
| | F | 31 | 114.4 | 35.3 | | |
| Simple RT | M | 21 | 346.8 | 50.6 | -1.04 | .30 |
| | F | 29 | 363.2 | 57.6 | | |
| Simple MT | M | 20 | 307.9 | 86.9 | .151 | .88 |
| | F | 28 | 312.2 | 103.4 | | |
| Simple Errors | M | 23 | 2.1 | 2.8 | -.78 | .44 |
| | F | 29 | 2.8 | 3.4 | | |
| Choice RT | M | 23 | 423.0 | 60.7 | -1.48 | .15 |
| | F | 31 | 456.9 | 96.8 | | |
| Choice MT | M | 21 | 331.8 | 72.3 | .72 | .48 |
| | F | 30 | 316.7 | 75.7 | | |
| Choice Errors | M | 22 | 1.6 | 2.2 | -.80 | .43 |
| | F | 31 | 2.3 | 3.4 | | |
| OMO RT | M | 23 | 831.4 | 264.5 | -.32 | .75 |
| | F | 30 | 854.6 | 265.7 | | |
| OMO MT | M | 21 | 361.9 | 93.9 | .08 | .94 |
| | F | 32 | 360.0 | 74.7 | | |
| OMO Errors | M | 22 | 9.1 | 7.9 | -1.01 | .32 |
| | F | 30 | 11.7 | 10.0 | | |

Table 4-7

Descriptive Statistics (in ms) by Handedness
Across Elementary Cognitive Task Performance

| Elementary Cognitive Task | | *N* | *M* | *SD* | *t* | *p* |
|---|---|---|---|---|---|---|
| Visual IT | R | 33 | 115.4 | 35.6 | 1.58 | .12 |
| | NR[a] | 20 | 100.1 | 31.7 | | |
| Simple RT | R | 33 | 347.8 | 37.8 | -1.27 | .22 |
| | NR | 17 | 372.9 | 76.9 | | |
| Simple MT | R | 30 | 300.0 | 81.0 | -.97 | .34 |
| | NR | 18 | 327.7 | 117.1 | | |
| Simple Errors | R | 33 | 2.3 | 3.2 | -.55 | .58 |
| | NR | 19 | 2.8 | 3.2 | | |
| Choice RT | R | 34 | 428.0 | 72.7 | -1.66 | .10 |
| | NR | 20 | 466.9 | 98.4 | | |
| Choice MT | R | 33 | 313.2 | 71.2 | -1.27 | .21 |
| | NR | 18 | 340.6 | 77.8 | | |
| Choice Errors | R | 34 | 1.5 | 2.1 | -1.45 | .16 |
| | NR | 19 | 2.9 | 4.0 | | |
| OMO RT | R | 34 | 811.2 | 248.8 | -1.24 | .22 |
| | NR | 19 | 904.2 | 283.3 | | |
| OMO MT | R | 34 | 365.1 | 92.8 | .51 | .61 |
| | NR | 19 | 353.0 | 59.4 | | |
| Errors | R | 33 | 9.8 | 8.2 | -.80 | .43 |
| | NR | 19 | 11.9 | 10.8 | | |

Note: [a]NR = non-right

As can be seen from Table 4-8, age significantly correlated with performance on almost all of the ECT tasks, and in the expected direction. The results in this study are consistent with research that suggests the speed of mental processing improves with age (Nettelbeck, 1987).

Table 4-8

Pearson Product-Moment Correlations Between Age (in months) and Elementary Cognitive Task Performance

| Elementary Cognitive Task[a] | *r* | *p* |
|---|---|---|
| Visual IT | -.34* | .01 |
| Simple RT | -.29* | .04 |
| Simple MT | -.32* | .03 |
| Simple Errors | -.07 | .63 |
| Choice RT | -.54* | .00 |
| Choice MT | -.42* | .00 |
| Choice Errors | -.43* | .00 |
| OMO RT | -.47* | .00 |
| OMO MT | -.03 | .84 |
| OMO Errors | -.41* | .00 |

Note: [a]Refer to Table 4-5 for *M*s and *SD*s; *$p < .05$

As can be seen in Table 4-9, SES significantly correlated with performance on only one of the RT tasks, Choice RT. These results are not surprising, given the nature of the tasks. As mentioned previously in this study, ECTs are simple, elementary tasks

that require no past learned information or content to perform them (Eysenck, 1994; Jensen, 1998). Although only one significant relationship with SES was found, any potential confounding effects of SES were controlled for in later analyses in this study.

Table 4-9

Pearson Product-Moment Correlations Between SES and Elementary Cognitive Task Performance

| Elementary Cognitive Task[a] | *r* | *p* |
|---|---|---|
| Visual IT | -.18 | .20 |
| Simple RT | .07 | .62 |
| Simple MT | -.05 | .72 |
| Simple Errors | -.05 | .71 |
| Choice RT | .35* | .01 |
| Choice MT | -.01 | .94 |
| Choice Errors | -.09 | .55 |
| OMO RT | .27 | .05 |
| OMO MT | -.12 | .38 |
| OMO Errors | -.05 | .71 |

Note: [a]Refer to Table 4-5 for *M*s and *SD*s; $^{*}p < .05$

Neuroanatomical Variables

Table 4-10 presents descriptive statistics for the neuroanatomical variables in this study. Additional analyses were conducted to test for mean differences by age, sex,

handedness, and SES on all of the neuroanatomical variables. These results are displayed in Tables 4-11 to 4-14.

As can be seen in Table 4-11, significant sex differences were found for several of the neuroanatomical variables, including volume of the cerebrum and cerebellum and surface area of the corpus callosum. Significant cerebral differences are expected and exist in the general population (Reiss et al., 1996). It is also important to note that these findings may be the result of random variation and further replication is needed.

As can be seen in Table 4-12, a significant handedness difference was found for one neuroanatomical region, the left pars triangularis. No other significant handedness differences were found.

As can be seen in Tables 4-13 and 4-14, no significant age or SES differences were found for any of the neuroanatomical variables.

Table 4-10

Descriptive Statistics for the Neuroanatomical Regions

| Neuroanatomical Region | *N* | *M* | *SD* | Range |
|---|---|---|---|---|
| Cerebral Volume (cc) | | | | |
| Left BV | 56 | 576 | 44 | 488-680 |
| Right BV | 56 | 585 | 46 | 489-702 |
| Total BV | 56 | 1161 | 88 | 977-1379 |
| Asym BV | 56 | -.02 | .03 | -.10-.06 |
| Inferior Frontal Gyrus ($cm^2$) | | | | |
| Left PT | 56 | 2.84 | .69 | 1.51-4.63 |
| Right PT | 56 | 2.65 | .70 | 1.16-3.72 |
| Asym PT | 56 | .07 | .32 | -.55-.89 |
| Planum Temporale ($cm^2$) | | | | |
| Left Planum | 56 | 3.03 | .82 | 1.24-5.33 |
| Right Planum | 56 | 2.58 | .94 | .27-4.89 |
| Planar Asym | 56 | .19 | .43 | -.81-1.66 |
| Left Parietale | 56 | 1.42 | .91 | .07-4.11 |
| Right Parietale | 56 | 1.42 | .79 | .11-3.10 |
| Parietale Asym | 56 | -.06 | .86 | -1.82-1.79 |
| Heschl's Gyrus ($cm^2$) | | | | |
| Left H1 | 56 | 4.04 | .84 | 2.33-6.20 |
| Right H1 | 56 | 3.53 | .69 | 2.09-5.44 |
| Left H2 | 56 | .86 | .93 | .07-3.00 |
| Right H2 | 56 | 1.02 | .85 | .08-2.72 |

Table 4-10-continued

| Neuroanatomical Region | *N* | *M* | *SD* | Range |
|---|---|---|---|---|
| Corpus Callosum ($cm^2$) | | | | |
| Rostrum | 56 | .25 | .12 | .05-.79 |
| Genu | 56 | 1.18 | .27 | .64-1.76 |
| Body | 56 | 2.27 | .33 | 1.46-3.04 |
| Isthmus | 56 | .53 | .11 | .27-.78 |
| Splenium | 56 | 1.47 | .24 | 1.03-1.89 |
| Total CC | 56 | 5.69 | .81 | 3.89-7.52 |
| Cerebellum (cc) | | | | |
| Left Ant Lobe | 56 | 6.97 | .96 | 5.20-8.70 |
| Right Ant Lobe | 56 | 6.79 | 1.09 | 4.7-9.6 |
| Total Ant Lobe | 56 | 13.76 | 1.91 | 10.00-17.90 |
| Asym Ant Lobe | 56 | .03 | .10 | -.40-.22 |

Table 4-11

Descriptive Statistics by Sex Across Neuroanatomical Regions

| Neuroanatomical Region | | *N* | M | *SD* | *t* | *p* |
|---|---|---|---|---|---|---|
| Left BV | M | 24 | 594 | 38 | 2.77* | .01 |
| | F | 32 | 563 | 44 | | |
| Right BV | M | 24 | 601 | 41 | 2.52* | .02 |
| | F | 32 | 572 | 45 | | |
| Total BV | M | 24 | 1195 | 77 | 2.70* | .01 |
| | F | 32 | 1135 | 87 | | |
| Asym BV | M | 24 | -.01 | .03 | .47 | .64 |
| | F | 32 | -.02 | .03 | | |
| Left PT | M | 24 | 2.90 | .61 | .54 | .59 |
| | F | 32 | 2.79 | .75 | | |
| Right PT | M | 24 | 2.79 | .79 | 1.35 | .18 |
| | F | 32 | 2.54 | .61 | | |
| Asym PT | M | 24 | .053 | .388 | -.42 | .67 |
| | F | 32 | .090 | .265 | | |
| Left Planum | M | 24 | 3.13 | .81 | .81 | .42 |
| | F | 32 | 2.95 | .84 | | |
| Right Planum | M | 24 | 2.78 | .96 | 1.39 | .17 |
| | F | 32 | 2.43 | .91 | | |
| Planar Asym | M | 24 | .14 | .44 | -.65 | .52 |
| | F | 32 | .22 | .43 | | |
| Left Parietale | M | 24 | 1.45 | 1.01 | .18 | .86 |
| | F | 32 | 1.40 | .85 | | |
| Right Parietale | M | 24 | 1.41 | .71 | -.15 | .88 |
| | F | 32 | 1.44 | .85 | | |
| Parietale Asym | M | 24 | -.08 | .83 | -.11 | .92 |
| | F | 32 | -.05 | .89 | | |

Table 4-11-continued

| Neuroanatomical Region | | $N$ | $M$ | $SD$ | $t$ | $p$ |
|---|---|---|---|---|---|---|
| Left H1 | M | 24 | 4.02 | .69 | -.11 | .92 |
| | F | 32 | 4.05 | .95 | | |
| Right H1 | M | 24 | 3.65 | .60 | 1.19 | .24 |
| | F | 32 | 3.43 | .75 | | |
| Left H2 | M | 24 | .73 | .80 | -.87 | .39 |
| | F | 32 | .95 | 1.02 | | |
| Right H2 | M | 24 | 1.00 | .85 | -.12 | .90 |
| | F | 32 | 1.03 | .86 | | |
| Rostrum | M | 24 | .29 | .14 | 2.07 | .04 |
| | F | 32 | .23 | .09 | | |
| Genu | M | 24 | 1.24 | .27 | 1.30 | .20 |
| | F | 32 | 1.14 | .27 | | |
| Body | M | 24 | 2.40 | .31 | $2.49^{*}$ | .02 |
| | F | 32 | 2.18 | .33 | | |
| Isthmus | M | 24 | .54 | .11 | .49 | .63 |
| | F | 32 | .52 | .11 | | |
| Splenium | M | 24 | 1.54 | .21 | 1.89 | .06 |
| | F | 32 | 1.42 | .25 | | |
| Total CC | M | 24 | 5.97 | .72 | $2.33^{*}$ | .02 |
| | F | 32 | 5.48 | .82 | | |
| Left Ant Lobe | M | 24 | 7.55 | .74 | $4.58^{*}$ | .00 |
| | F | 32 | 6.54 | .87 | | |
| Right Ant Lobe | M | 24 | 7.08 | .75 | 1.88 | .07 |
| | F | 32 | 6.57 | 1.26 | | |
| Total Ant Lobe | M | 24 | 14.62 | 1.40 | $3.35^{*}$ | .00 |
| | F | 32 | 13.11 | 1.99 | | |
| Asym Ant Lobe | M | 24 | .07 | .08 | $2.22^{*}$ | .03 |
| | F | 32 | .01 | .12 | | |

Note: $^{*}p < .05$

Table 4-12

Descriptive Statistics by Handedness Across Neuroanatomical Regions

| Neuroanatomical Region | | *N* | M | *SD* | *t* | *p* |
|---|---|---|---|---|---|---|
| Left BV | R | 37 | 579 | 42 | .61 | .55 |
| | NR[a] | 19 | 571 | 49 | | |
| Right BV | R | 37 | 587 | 41 | .45 | .65 |
| | NR | 19 | 581 | 55 | | |
| Total BV | R | 37 | 1165 | 80 | .54 | .59 |
| | NR | 19 | 1152 | 104 | | |
| Asym BV | R | 37 | -.01 | .03 | .27 | .79 |
| | NR | 19 | -.01 | .02 | | |
| Left PT | R | 37 | 3.00 | .63 | 2.56* | .01 |
| | NR | 19 | 2.52 | .71 | | |
| Right PT | R | 37 | 2.65 | .65 | .07 | .94 |
| | NR | 19 | 2.64 | .80 | | |
| Asym PT | R | 37 | .13 | .30 | 1.81 | .08 |
| | NR | 19 | -.03 | .34 | | |
| Left Planum | R | 37 | 3.11 | .88 | 1.12 | .27 |
| | NR | 19 | 2.85 | .68 | | |
| Right Planum | R | 37 | 2.60 | .86 | .20 | .84 |
| | NR | 19 | 2.55 | 1.11 | | |
| Planar Asym | R | 37 | .19 | .43 | .112 | .91 |
| | NR | 19 | .18 | .44 | | |
| Left Parietale | R | 37 | 1.30 | .83 | -1.42 | .16 |
| | NR | 19 | 1.66 | 1.02 | | |
| Right Parietale | R | 37 | 1.45 | .73 | .41 | .68 |
| | NR | 19 | 1.36 | .90 | | |
| Parietale Asym | R | 37 | -.18 | .86 | -1.42 | .16 |
| | NR | 19 | .16 | .83 | | |

Table 4-12-continued

| Neuroanatomical Region | | *N* | *M* | *SD* | *t* | *p* |
|---|---|---|---|---|---|---|
| Left H1 | R | 37 | 3.98 | .80 | -.69 | .49 |
| | NR | 19 | 4.15 | .92 | | |
| Right H1 | R | 37 | 3.59 | .73 | .97 | .34 |
| | NR | 19 | 3.40 | .60 | | |
| Left H2 | R | 37 | .92 | 1.01 | .70 | .49 |
| | NR | 19 | .73 | .75 | | |
| Right H2 | R | 37 | .95 | .87 | -.77 | .44 |
| | NR | 19 | 1.14 | .81 | | |
| Rostrum | R | 37 | .26 | .12 | .19 | .85 |
| | NR | 19 | .25 | .11 | | |
| Genu | R | 37 | 1.22 | .25 | 1.54 | .13 |
| | NR | 19 | 1.10 | .31 | | |
| Body | R | 37 | 2.28 | .29 | .03 | .98 |
| | NR | 19 | 2.27 | .42 | | |
| Isthmus | R | 37 | .54 | .10 | .51 | .62 |
| | NR | 19 | .52 | .12 | | |
| Splenium | R | 37 | 1.51 | .23 | 1.89 | .06 |
| | NR | 19 | 1.39 | .25 | | |
| Total CC | R | 37 | 5.78 | .73 | 1.12 | .27 |
| | NR | 19 | 5.52 | .95 | | |
| Left Ant Lobe | R | 37 | 6.98 | .91 | .09 | .93 |
| | NR | 19 | 6.96 | 1.07 | | |
| Right Ant Lobe | R | 37 | 6.79 | 1.10 | .04 | .97 |
| | NR | 19 | 6.78 | 1.11 | | |
| Total Ant Lobe | R | 37 | 13.77 | 1.85 | .08 | .94 |
| | NR | 19 | 13.73 | 2.06 | | |
| Asym Ant Lobe | R | 37 | .03 | .11 | .33 | .74 |
| | NR | 19 | .02 | .09 | | |

Note: $^{*}p < .05$; [a]NR = non-right

Table 4-13

Pearson Product-Moment Correlations Between Age (in months) and Neuroanatomical Regions

| Neuroanatomical Region[a] | $r$ | $p$ |
|---|---|---|
| Left BV | -.10 | .47 |
| Right BV | -.17 | .22 |
| Total BV | -.14 | .32 |
| Asym BV | .18 | .19 |
| Left PT | .07 | .60 |
| Right PT | .11 | .42 |
| Asym PT | -.04 | .76 |
| Left Planum | .03 | .80 |
| Right Planum | -.00 | .98 |
| Planar Asym | .07 | .63 |
| Left Parietale | .15 | .27 |
| Right Parietale | -.01 | .95 |
| Parietale Asym | .14 | .32 |
| Left H1 | .24 | .08 |
| Right H1 | .05 | .74 |
| Left H2 | -.19 | .17 |
| Right H2 | .00 | .99 |
| Rostrum | -.13 | .34 |
| Genu | .08 | .56 |
| Body | .12 | .37 |
| Isthmus | .04 | .79 |
| Splenium | .12 | .37 |
| Total CC | .12 | .39 |
| Left Ant Lobe | -.01 | .96 |
| Right Ant Lobe | .08 | .58 |
| Total Ant Lobe | .04 | .77 |
| Asym Ant Lobe | -.14 | .29 |

Note: [a]Refer to Table 4-10 for *M*s and *SD*s

Table 4-14

Pearson Product-Moment Correlations Between SES and Neuroanatomical Regions

| Neuroanatomical Region[a] | *r* | *p* |
|---|---|---|
| Left BV | .22 | .11 |
| Right BV | .26 | .06 |
| Total BV | .24 | .07 |
| Asym BV | -.11 | .42 |
| Left PT | -.06 | .65 |
| Right PT | -.21 | .13 |
| Asym PT | .11 | .44 |
| Left Planum | -.01 | .96 |
| Right Planum | -.13 | .35 |
| Planar Asym | .11 | .44 |
| Left Parietale | .11 | .42 |
| Right Parietale | .16 | .24 |
| Parietale Asym | .05 | .73 |
| Left H1 | -.14 | .30 |
| Right H1 | -.18 | .20 |
| Left H2 | -.06 | .68 |
| Right H2 | -.05 | .73 |
| Rostrum | .22 | .10 |
| Genu | .18 | .18 |
| Body | .11 | .43 |
| Isthmus | .10 | .47 |
| Splenium | .01 | .92 |
| Total CC | .15 | .27 |
| Left Ant Lobe | .24 | .08 |
| Right Ant Lobe | .25 | .06 |
| Total Ant Lobe | .26 | .05 |
| Asym Ant Lobe | -.07 | .62 |

Note: [a]Refer to Table 4-10 for *M*s and *SD*s

## Hypothesis Testing

The following sections present results of the various correlation and multiple regression procedures used to test the main hypotheses of the study.

### Research Question 1

Is naming speed strongly associated with reading achievement, independent of phonological awareness? This hypothesis was investigated through the use of correlation analyses and simultaneous multiple regression analyses.

#### Psychometric Comparisons

Table 4-15 presents correlations among the measures of naming speed. As can be seen from the table, all three RAN tasks correlate significantly with each other (all *ps* < .05). Given the substantial significant intercorrelations among the naming speed tasks, a composite score (NS Composite) was computed by averaging the mean *z* score for each naming speed task.

Table 4-15

Pearson Product-Moment Correlations Among Measures of Naming Speed

| Psychometric Test | RAN Colors | RAN Numbers | RAN Letters | NS Composite[a] |
|---|---|---|---|---|
| RAN Colors | -- | $.71^{*}$ | $.53^{*}$ | $.86^{*}$ |
| RAN Numbers | $.71^{*}$ | -- | $.73^{*}$ | $.90^{*}$ |
| RAN Letters | $.53^{*}$ | $.73^{*}$ | -- | $.84^{*}$ |
| NS Composite[a] | $.86^{*}$ | $.90^{*}$ | $.84^{*}$ | -- |

Note: [a]Sum of *z* scores across Naming Speed tasks; $^{*}p < .05$

Table 4-16 presents correlations among the measures of phonological awareness. As can be seen from the table, both of the phonological awareness tasks correlate significantly with each other (all *ps* < .05). Given the substantial significant intercorrelation between these two tasks, a composite score (PA Composite) was computed by averaging the mean *z* score for each phonological awareness task.

Table 4-16

Pearson Product-Moment Correlations Among Measures of Phonological Awareness

| Psychometric Test | Elision | LAC | PA Composite[a] |
|---|---|---|---|
| Elision | -- | .53* | .88* |
| LAC | .53* | -- | .88* |
| PA Composite[a] | .88* | .88* | -- |

Note: [a]Sum of *z* scores across Phonological Awareness tasks; *$p < .05$

Table 4-17 presents correlations among the measures of naming speed and phonological awareness. As can be seen from the table, several significant correlations were found among these measures. Specifically, significant relations were found between the Elision and RAN Numbers tasks ($r = -.29, p < .05$), the Elision and RAN Letters tasks ($r = -.42, p < .05$), and the PA composite score and RAN Letters task ($r = -.33, p < .05$).

Table 4-18 presents correlations among the measures of reading achievement. As the table shows, correlations are substantial and range from .54 to .94 (all *ps* < .05).

Table 4-17

Pearson Product-Moment Correlations Among
Measures of Naming Speed and Phonological Awareness

| Psychometric Test | Elision | LAC | PA Composite[b] |
|---|---|---|---|
| RAN Colors | -.05 | -.12 | -.10 |
| RAN Numbers | -.29* | -.12 | -.24 |
| RAN Letters | -.42* | -.16 | -.33* |
| NS Composite[a] | -.27 | -.17 | -.25 |

Note: [a]Naming Speed; [b]Phonological Awareness; $^{*}p < .05$

Table 4-19 presents correlations among the measures of naming speed and reading achievement. As can be seen from the table, all of the measures of reading achievement significantly correlate with the naming speed tasks, except for RAN Colors. Therefore, this task was not included in later analyses.

Table 4-18

Pearson Product-Moment Correlations Among
Measures of Reading Achievement

| Psychometric Test | Letter-Word ID | Passage Comp | Word Attack | Broad Reading | Basic Reading |
|---|---|---|---|---|---|
| Letter-Word ID | -- | .56* | .80* | .91* | .94* |
| Passage Comp | .56* | -- | .54* | .83* | .65* |
| Word Attack | .80* | .54* | -- | .77* | .87* |
| Broad Reading | .91* | .83* | .77* | -- | .92* |
| Basic Reading | .94* | .65* | .87* | .92* | -- |

Note: $^{*}p < .05$

Table 4-19

Pearson Product-Moment Correlations Among
Measures of Naming Speed and Reading Achievement

| Psychometric Test | Letter-Word ID | Passage Comp | Word Attack | Broad Reading | Basic Reading |
|---|---|---|---|---|---|
| RAN Colors | -.06 | -.14 | -.08 | -.14 | -.13 |
| RAN Numbers | -.38* | -.32* | -.37* | -.43* | -.41* |
| RAN Letters | -.38* | -.33* | -.37* | -.43* | -.44* |
| NS Composite[a] | -.30* | -.31* | -.29* | -.38* | -.36* |

Note: [a]Naming Speed; $^{*}p < .05$

Table 4-20 presents correlations among the measures of phonological awareness and reading achievement. As can be seen from the table, all of the phonological awareness tasks correlate significantly with the reading measures, except for the LAC and Passage Comprehension. In addition, because the LAC did not correlate significantly with any of the naming speed tasks, it was not included in later analyses.

Table 4-20

Pearson Product-Moment Correlations Among
Measures of Phonological Awareness and Reading Achievement

| Psychometric Test | Letter-Word ID | Passage Comp | Word Attack | Broad Reading | Basic Reading |
|---|---|---|---|---|---|
| Elision | .46* | .43* | .53* | .50* | .55* |
| LAC | .27* | .25 | .32* | .32* | .35* |
| PA Composite[a] | .42* | .39* | .49* | .47* | .51* |

Note: [a]Phonological Awareness; $^{*}p < .05$

Multiple Regression Analyses

Based on the results of the correlation analyses, a significant relation was found between naming speed and reading achievement. In addition, a significant relation was found between two measures of naming speed (RAN Letters and RAN Numbers) and the Elision task, and between RAN Letters and the PA composite score. Therefore, these variables were chosen as independent variables in a series of simultaneous multiple regression analyses. Although the LAC was not significantly related to naming speed in the previous analyses, the PA composite score was included in the multiple regression analyses to represent a comprehensive measure of phonological awareness. In simultaneous or "forced entry" multiple regression, all of the variables are entered into the regression model at the same time. This method was chosen because it is useful for determining the relative influence of each of the variables. In addition, it can be used to determine the extent to which a variable predicts an outcome and the relative importance of the various predictors to the model. For each measure of reading achievement, three different models were used (models 1a, 1b, and 1c) to investigate the relationship between naming speed, phonological awareness, and reading achievement. In addition to these variables, age was entered and controlled for in each analysis, based on the significant relationship that was found between age and these variables in previous analyses. It is important to note that for each model, both the $R^2$ and the adjusted $R^2$ values are reported. However, a somewhat better estimate is the adjusted $R^2$, because the $R^2$ value tends to be biased upward. This bias is greater when the sample size ($N$) is small or the number of predictors in the model is large (Agresti & Finlay, 1997). Tables 4-21 to 4-25 present results from these analyses.

Table 4-21

Simultaneous Multiple Regression of Naming Speed
and Phonological Awareness on Letter-Word Identification

| Model | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| Ia | Age | .25* | .20* | -2.775 | -.184 | -1.405 | .17 |
| | Elision | | | 1.135 | .317 | 2.255* | .03 |
| | RAN Letters | | | -.625 | -.294 | -2.083* | .04 |
| 1b | Age | .28* | .23* | -3.291 | -.219 | -1.672 | .10 |
| | Elision | | | 1.260 | .352 | 2.694* | .01 |
| | RAN Numbers | | | -.750 | -.337 | -2.530* | .02 |
| 1c | Age | .25* | .20* | -3.475 | -.231 | -1.706 | .10 |
| | PA Composite[a] | | | 5.543 | .315 | 2.264* | .03 |
| | RAN Letters | | | -.713 | -.336 | -2.484* | .02 |

Note: [a]Phonological Awareness; *$p < .05$

As can be seen from Table 4-21, all three models are statistically significant. The best model is 1b, where the three variables in combination account for 23% of the variance in the Letter-Word ID score ($F = 6.038$, $df = 50$, $p < .05$). Both the Elision and RAN Numbers tasks each have a significant effect in the overall model, with the Elision task being a slightly better predictor of overall performance ($\beta = .352$, $p < .05$).

Table 4-22

Simultaneous Multiple Regression of Naming Speed and Phonological Awareness on Passage Comprehension

| Model | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| 1a | Age | .26* | .22* | -3.794 | -.286 | -2.199* | .03 |
| | Elision | | | 1.111 | .352 | 2.529* | .02 |
| | RAN Letters | | | -.463 | -.247 | -1.765 | .08 |
| 1b | Age | .30* | .25* | -4.250 | -.320 | -2.480* | .02 |
| | Elision | | | 1.187 | .376 | 2.913* | .01 |
| | RAN Numbers | | | -.601 | -.307 | -2.330* | .02 |
| 1c | Age | .26* | .22* | -4.475 | -.337 | -2.514* | .02 |
| | PA Composite[a] | | | 5.408 | .348 | 2.527* | .02 |
| | RAN Letters | | | -.549 | -.293 | -2.190* | .03 |

Note: [a]Phonological Awareness; *$p < .05$

As can be seen from Table 4-22, all three models are statistically significant. The best model is 1b, where the three variables in combination account for 25% of the variance in the Passage Comprehension score ($F = 6.593$, $df = 50$, $p < .05$). Both the Elision and RAN Numbers tasks each have a significant effect in the overall model, with the Elision task being a slightly better predictor of overall performance ($\beta = .376$, $p < .05$). In addition, age has a significant effect in the overall model ($\beta = -.320$, $p < .05$).

Table 4-23

Simultaneous Multiple Regression of Naming Speed and Phonological Awareness on Word Attack

| Model | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| 1a | Age | .38* | .35* | -5.277 | -.347 | -2.946* | .01 |
| | Elision | | | 1.584 | .439 | 3.478* | .00 |
| | RAN Letters | | | -.603 | -.281 | -2.213* | .03 |
| 1b | Age | .42* | .39* | -5.857 | -.385 | -3.327* | .00 |
| | Elision | | | 1.686 | .467 | 4.039* | .00 |
| | RAN Numbers | | | -.775 | -.345 | -2.923* | .01 |
| 1c | Age | .41* | .37* | -6.390 | -.420 | 3.530* | .00 |
| | PA Composite[a] | | | 8.309 | .469 | 3.831* | .00 |
| | RAN Letters | | | -.706 | -.329 | -2.768* | .01 |

Note: [a]Phonological Awareness; *$p < .05$

As can be seen from Table 4-23, all three models are statistically significant. The best model is 1b, where the three variables in combination account for 39% of the variance in the Word Attack score ($F = 11.765$, $df = 51$, $p < .05$). Both the Elision and RAN Numbers tasks each have a significant effect in the overall model, with the Elision task being a better predictor of overall performance ($\beta = .467$, $p < .05$). In addition, age has a significant effect in the overall model (($\beta = -.385$, $p < .05$).

Table 4-24

Simultaneous Multiple Regression of Naming Speed
and Phonological Awareness on Broad Reading Skills

| Model | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| 1a | Age | .30* | .26* | -2.434 | -.187 | -1.481 | .15 |
| | Elision | | | 1.067 | .345 | 2.547* | .01 |
| | RAN Letters | | | -.610 | -.333 | -2.443* | .02 |
| 1b | Age | .34* | .30* | -2.936 | -.226 | -1.806 | .08 |
| | Elision | | | 1.189 | .384 | 3.078* | .00 |
| | RAN Numbers | | | -.731 | -.380 | -2.985* | .00 |
| 1c | Age | .31* | .27* | -3.147 | -.242 | -1.869 | .07 |
| | PA Composite[a] | | | 5.450 | .358 | 2.692* | .01 |
| | RAN Letters | | | -.685 | -.373 | -2.887* | .01 |

Note: [a]Phonological Awareness; $^*p < .05$

As can be seen from Table 4-24, all three models are statistically significant. The best model is 1b, where the three variables in combination account for 30% of the variance in the Broad Reading Skills score ($F = 8.094$, $df = 50$, $p < .05$). Both the Elision and RAN Numbers tasks each have a significant effect in the overall model, with the Elision task being a slightly better predictor of overall performance ($\beta = .384$, $p < .05$).

Table 4-25

Simultaneous Multiple Regression of Naming Speed and Phonological Awareness on Basic Reading Skills

| Model | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| 1a | Age | .35* | .31* | -3.132 | -.207 | -1.696 | .10 |
| | Elision | | | 1.461 | .406 | 3.104* | .00 |
| | RAN Letters | | | -.673 | -.316 | -2.399* | .02 |
| 1b | Age | .38* | .34* | -3.667 | -.243 | -2.001 | .05 |
| | Elision | | | 1.601 | .445 | 3.673* | .00 |
| | RAN Numbers | | | -.795 | -.356 | -2.880* | .01 |
| 1c | Age | .37* | .33* | -4.141 | -.274 | -2.206* | .03 |
| | PA Composite[a] | | | 7.603 | .430 | 3.369* | .00 |
| | RAN Letters | | | -.771 | -.362 | -2.916* | .01 |

Note: [a]Phonological Awareness; $^{*}p < .05$

As can be seen from Table 4-25, all three models are statistically significant. The best model is 1b, where the three variables in combination account for 34% of the variance in the Basic Reading Skills score ($F = 9.558$, $df = 50$, $p < .05$). Both the Elision and RAN Numbers tasks each have a significant effect in the overall model, with the Elision task being a better predictor of overall performance ($\beta = .445$, $p < .05$).

For each of the reading measures, naming speed and phonological awareness remained significant predictors in each model. Therefore, in the next section, nonphonological predictors of reading, such as cognitive ability and processing speed,

will be included in each model to further assess the relationship between naming speed, phonological awareness, and reading achievement.

Research Question 2

Is naming speed associated with "nonphonological" predictors of reading, such as cognitive ability and processing speed, and if so, how does this affect naming speed's relationship with reading achievement? This hypothesis was investigated through the use of correlation analyses and simultaneous multiple regression analyses.

Psychometric Comparisons

Cognitive Ability. Table 4-26 presents correlations among general cognitive ability (BCA) and the measures of naming speed. As can be seen from the table, all three naming speed tasks, including the NS composite score significantly correlate with cognitive ability. These relations were investigated further in the study.

Table 4-26

Pearson Product-Moment Correlations Among Measures of Naming Speed and Cognitive Ability

| Psychometric Test | BCA |
|---|---|
| RAN Colors | -.34* |
| RAN Numbers | -.42* |
| RAN Letters | -.35* |
| NS Composite[a] | -.42* |

Note: [a]Naming Speed; *$p < .05$

Table 4-27 presents correlations among BCA and the measures of phonological awareness. As can be seen from the table, both of the phonological awareness tasks,

including the PA composite score, significantly correlate with cognitive ability. These relations were investigated further in the study.

Table 4-27

Pearson Product-Moment Correlations Among Measures of Phonological Awareness and Cognitive Ability

| Psychometric Test | BCA |
|---|---|
| Elision | $.34^*$ |
| LAC | $.50^*$ |
| PA Composite[a] | $.48^*$ |

Note: [a]Phonological Awareness; $^*p < .05$

Table 4-28 presents correlations among BCA and the measures of reading achievement. As can be seen from the table, all of the reading measures significantly correlate with cognitive ability. These relations were investigated further in the study.

Table 4-28

Pearson Product-Moment Correlations Among Cognitive Ability and Measures of Reading Achievement

| Psychometric Test | Letter-Word ID | Passage Comp | Word Attack | Broad Reading | Basic Reading |
|---|---|---|---|---|---|
| BCA | $.44^*$ | $.56^*$ | $.45^*$ | $.55^*$ | $.47^*$ |

Note: $^*p < .05$

Multiple Regression Analyses

Cognitive Ability. Based on the results of the correlation analyses, a significant relation was found between naming speed, phonological awareness, and cognitive ability. Therefore, the variables that were chosen previously as independent variables in a series of simultaneous multiple regression analyses were analyzed again, with the inclusion of BCA in each of the models. For each measure of reading achievement, three different models were used (models 2a, 2b, and 2c) to investigate the relationship between naming speed, phonological awareness, cognitive ability, and reading achievement. In addition to these variables, age was entered and controlled for in each analysis, based on the significant relationship that was found between age and these variables in previous analyses. Tables 4-29 to 4-33 present the results of these analyses.

As can be seen from Table 4-29, all three models are statistically significant. The best model is 2b, where the four variables in combination account for 27% of the variance in the Letter-Word ID score ($F = 5.353$, $df = 48$, $p < .05$). After the inclusion of cognitive ability, the Elision remains the only task with a significant effect in the overall model ($\beta = .346$, $p < .05$).

As can be seen from Table 4-30, all three models are statistically significant. The best models are 2a and 2b, where the four variables in combination account for 36% of the variance in the Passage Comp score (2a: $F = 7.609$, $df = 48$, $p < .05$; 2b: $F = 7.829$, $df = 48$, $p < .05$). Both BCA and the Elision tasks have a significant effect in each model, with BCA being a slightly better predictor of overall performance (2a: $\beta = .434$, $p < .05$; 2b: $\beta = .410$, $p < .05$). Age also has a significant effect in the overall model ($\beta = -.299$, $p < .05$).

As can be seen from Table 4-31, all three models are statistically significant. The best model is 2b, where the four variables in combination account for 39% of the variance in the Word Attack score ($F = 8.920$, $df = 49$, $p < .05$). After the inclusion of cognitive ability, the Elision remains the only task with a significant effect in the overall model ($\beta = .423$, $p < .05$). Age also has a significant effect in the overall model ($\beta = -.365$, $p < .05$).

As can be seen from Table 4-32, all three models are statistically significant. The best model is 2b, where the four variables in combination account for 37% of the variance in the Broad Reading Skills score ($F = 8.170$, $df = 48$, $p < .05$). Both BCA and the Elision task each have a significant effect in the overall model, with the Elision being only a slightly better predictor of overall performance ($\beta = .337$, $p < .05$).

As can be seen from Table 4-33, all three models are statistically significant. The best model is 2b, where the four variables in combination account for 36% of the variance in the Basic Reading Skills score ($F = 7.720$, $df = 48$, $p < .05$). After the inclusion of cognitive ability, the Elision remains the only task with a significant effect in the overall model ($\beta = .417$, $p < .05$).

As can be seen from the results of the multiple regression analyses, for each of the measures of reading achievement, when BCA was added to each model, the Elision task remained a strong, significant predictor. The RAN task also made a contribution to each model, but it was only marginally significant. In the next section, the relationship between naming speed, phonological awareness, and processing speed will be investigated. If a significant relation is determined, then the relevant processing speed variables will be included in a series of multiple regression analyses.

Table 4-29

Simultaneous Multiple Regression of Naming Speed, Phonological Awareness, and Cognitive Ability on Letter-Word Identification

| Model | Variables | $R^2$ | Adjusted $R^2$ | *b* | $\beta$ | *t* | *p* |
|---|---|---|---|---|---|---|---|
| 2a | Age | .32* | .25* | -3.088 | -.204 | -1.554 | .13 |
| | BCA | | | .336 | .253 | 1.878 | .07 |
| | Elision | | | 1.121 | .314 | 2.236* | .03 |
| | RAN Letters | | | -.447 | -.211 | -1.452 | .15 |
| 2b | Age | .33* | .27* | -3.415 | -.226 | -1.707 | .10 |
| | BCA | | | .291 | .219 | 1.588 | .12 |
| | Elision | | | 1.235 | .346 | 2.593* | .01 |
| | RAN Numbers | | | -.540 | -.245 | -1.710 | .09 |
| 2c | Age | .29* | .23* | -3.578 | -.237 | -1.709 | .10 |
| | BCA | | | .274 | .206 | 1.432 | .16 |
| | PA Composite[a] | | | 4.827 | .277 | 1.857 | .07 |
| | RAN Letters | | | -.584 | -.275 | -1.946 | .06 |

Note: [a]Phonological Awareness; *$p < .05$

Table 4-30

Simultaneous Multiple Regression of Naming Speed, Phonological Awareness, and Cognitive Ability on Passage Comprehension

| Model | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| 2a | Age | .41* | .36* | -3.786 | -.283 | -2.317* | .03 |
| | BCA | | | .510 | .434 | 3.466* | .00 |
| | Elision | | | .878 | .278 | 2.130* | .04 |
| | RAN Letters | | | -.245 | -.131 | -.968 | .34 |
| 2b | Age | .42* | .36* | -3.997 | -.299 | -2.422* | .02 |
| | BCA | | | .482 | .410 | 3.181* | .00 |
| | Elision | | | .937 | .296 | 2.384* | .02 |
| | RAN Numbers | | | -.315 | -.162 | -1.211 | .23 |
| 2c | Age | .38* | .32* | -3.992 | -.299 | -2.294* | .03 |
| | BCA | | | .479 | .408 | 3.016* | .00 |
| | PA Composite[a] | | | 3.056 | .198 | 1.414 | .16 |
| | RAN Letters | | | -.364 | -.194 | -1.460 | .15 |

Note: [a]Phonological Awareness; *$p < .05$

Table 4-31

Simultaneous Multiple Regression of Naming Speed, Phonological Awareness, and Cognitive Ability on Word Attack

| Model | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| 2a | Age | .42* | .37* | -5.136 | -.338 | -2.823* | .00 |
| | BCA | | | .368 | .276 | 2.248* | .03 |
| | Elision | | | 1.422 | .397 | 3.106* | .00 |
| | RAN Letters | | | -.417 | -.196 | -1.481 | .15 |
| 2b | Age | .44* | .39* | -5.545 | -.365 | -3.056* | .00 |
| | BCA | | | .313 | .234 | 1.881 | .07 |
| | Elision | | | 1.517 | .423 | 3.520* | .00 |
| | RAN Numbers | | | -.568 | -.257 | -1.986 | .05 |
| 2c | Age | .41* | .36* | -5.983 | -.394 | -3.151* | .00 |
| | BCA | | | .266 | .199 | 1.536 | .13 |
| | PA Composite[a] | | | 7.038 | .403 | 2.995* | .00 |
| | RAN Letters | | | -.576 | -.270 | -2.119* | .04 |

Note: [a]Phonological Awareness; * $p < .05$

Table 4-32

Simultaneous Multiple Regression of Naming Speed, Phonological Awareness, and Cognitive Ability on Broad Reading Skills

| Model | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| 2a | Age | .42* | .36* | -2.602 | -.197 | -1.622 | .11 |
| | BCA | | | .425 | .366 | 2.945* | .01 |
| | Elision | | | .942 | .302 | 2.329* | .03 |
| | RAN Letters | | | -.414 | -.223 | -1.665 | .10 |
| 2b | Age | .43* | .37* | -2.879 | -.218 | -1.783 | .08 |
| | BCA | | | .387 | .334 | 2.616* | .01 |
| | Elision | | | 1.052 | .337 | 2.735* | .01 |
| | RAN Numbers | | | -.483 | -.251 | -1.898 | .06 |
| 2c | Age | .39* | .34* | -2.982 | -.226 | -1.757 | .09 |
| | BCA | | | .376 | .324 | 2.428* | .02 |
| | PA Composite[a] | | | 3.924 | .258 | 1.863 | .07 |
| | RAN Letters | | | -.531 | -.287 | -2.184* | .03 |

Note: [a]Phonological Awareness; * $p < .05$

Table 4-33

Simultaneous Multiple Regression of Naming Speed, Phonological Awareness, and Cognitive Ability on Basic Reading Skills

| Model | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| 2a | Age | .40* | .35* | -3.191 | -.210 | -1.702 | .10 |
| | BCA | | | .352 | .263 | 2.087* | .04 |
| | Elision | | | 1.373 | .382 | 2.905* | .01 |
| | RAN Letters | | | -.488 | -.228 | -1.679 | .10 |
| 2b | Age | .41* | .36* | -3.534 | -.232 | -1.876 | .07 |
| | BCA | | | .305 | .228 | 1.767 | .08 |
| | Elision | | | 1.500 | .417 | 3.345* | .00 |
| | RAN Numbers | | | -.580 | -.262 | -1.954 | .06 |
| 2c | Age | .39* | .33* | -3.978 | -.261 | -2.029 | .05 |
| | BCA | | | .257 | .192 | 1.435 | .158 |
| | PA Composite[a] | | | 6.674 | .380 | 2.742* | .01 |
| | RAN Letters | | | -.643 | -.301 | -2.290* | .03 |

Note: [a]Phonological Awareness; *$p < .05$

Psychometric Comparisons

Processing Speed. Table 4-34 presents correlations among Visual IT and the three naming speed tasks. As can be seen from the table, only the RAN Colors task correlates significantly with Visual IT ($r = .31, p < .05$). Although this relationship is significant, it was not investigated further, since a significant relation was not found between the RAN Colors task and reading achievement in previous analyses.

Table 4-34

Pearson Product-Moment Correlations Among Measures of Naming Speed and Inspection Time

| Psychometric Test | Visual IT |
|---|---|
| RAN Colors | .31* |
| RAN Numbers | .17 |
| RAN Letters | -.01 |
| NS Composite[a] | .19 |

Note: [a]Naming Speed; $^{*}p < .05$

Table 4-35 presents correlations among Visual IT and the phonological awareness tasks. As can be seen from the table, none of the tasks correlate significantly with Visual IT. These relations were not investigated further in this study.

Table 4-35

Pearson Product-Moment Correlations Among Measures of Phonological Awareness and Inspection Time

| Psychometric Test | Visual IT |
|---|---|
| Elision | .08 |
| LAC | -.17 |
| PA Composite[a] | -.05 |

Note: [a]Phonological Awareness

Table 4-36 presents correlations among all of the ECT variables measured in this study. Within each task, correlations ranged from .06 to as high as .66 among all variables unique to that task. As expected, between tasks, the RTs and MTs of each of

the three tasks correlate significantly with the same variables of the tasks being compared (all *p*s < .05). Given these significant intercorrelations, two composite scores (RT Composite and MT Composite) were computed by averaging the mean *z* score for the RTs and MTs of each task.

Tables 4-37 to 4-38 present correlations among the measures of naming speed, phonological awareness, and RT. As can be seen from Table 4-37, many of the RT variables correlate significantly with the naming speed tasks. More specifically, the RAN Numbers and RAN Letters tasks that have been used thus far in the multiple regression analyses correlate significantly with many of the RT variables, including both of the composite scores.

As can be seen from Table 4-38, the phonological awareness tasks do not correlate as strongly with the RT variables as the naming speed tasks. It is interesting to note that significant correlations were only found for the MT and error variables associated with the Choice and OMO tasks, respectively.

Table 4-39 presents correlations among the ECT variables and the measures of reading achievement. As can be seen from the table, several significant correlations were found between the ECTs and the reading measures. It is interesting to note that the Visual IT task did not correlate with any of the naming speed or phonological awareness tasks, except for RAN Colors. As can be seen from the table, Visual IT correlates significantly with both Passage Comp ($r = .28, p < .05$) and Broad Reading Skills ($r = .30, p < .05$). The MT variables associated with the Simple and Choice RT tasks also correlate significantly with several of the reading measures, including Letter-Word ID, Passage Comp, Broad Reading Skills, and Basic Reading Skills.

Table 4-36

Pearson Product-Moment Correlations Among all Elementary Cognitive Tasks

| Elementary Cognitive Task | Visual IT | Simple RT | Simple MT | Simple Errors | Choice RT | Choice MT | Choice Errors | OMO RT | OMO MT | OMO Errors | RT Composite[a] | MT Composite[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Visual IT | -- | .10 | -.04 | .04 | .05 | .01 | .17 | .08 | -.06 | .23 | .06 | -.04 |
| Simple RT | .10 | -- | .61* | .23 | .56* | .44* | .51* | .49* | .14 | .35* | .83* | .30* |
| Simple MT | -.04 | .61* | -- | .06 | .38* | .68* | .42* | .38* | .36* | .46 | .55* | .58* |
| Simple Errors | .04 | .23 | .06 | -- | .28* | .17 | .38* | .00 | .13 | .28* | .21 | .17 |
| Choice RT | .05 | .56* | .38* | .28* | -- | .51* | .66* | .59* | -.02 | .44* | .86* | .18 |
| Choice MT | .01 | .44* | .68* | .17 | .51* | -- | .55* | .40* | .24* | .48* | .55* | .64* |
| Choice Errors | .17 | .51* | .42* | .38* | .66* | .55* | -- | .37* | .03 | .58* | .61* | .25 |
| OMO RT | .08 | .49* | .38* | .00 | .59* | .40* | .37* | -- | -.10 | .44* | .84* | .05 |
| OMO MT | -.06 | .14 | .36* | .13 | -.02 | .24* | .03 | -.10 | -- | .15 | -.01 | .91* |
| OMO Errors | .23 | .35* | .46 | .28* | .44* | .48* | .58* | .44* | .15 | -- | .50* | .27 |
| RT Composite[a] | .06 | .82* | .55* | .21 | .86* | .55* | .61* | .84* | -.01 | .50* | -- | .19 |
| MT Composite[b] | -.04 | .30* | .58* | .17 | .18 | .64* | .25 | .05 | .91* | .27 | .19 | -- |

Note: [a]Sum of $z$ scores across all Reaction Time variables; [b]Sum of z scores across all Movement Time variables; $^{*}p < .05$

Table 4-37

Pearson Product-Moment Correlations Among Measures of Naming Speed and Reaction Time

| Psychometric Test | Simple RT | Simple MT | Simple Errors | Choice RT | Choice MT | Choice Errors | OMO RT | OMO MT | OMO Errors | RT Composite[b] | MT Composite[c] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RAN Colors | .18 | .29* | .10 | .42* | .42* | .41* | .21 | .14 | .39* | .32* | .28* |
| RAN Numbers | .39* | .58* | .21 | .44* | .54* | .47* | .26 | .15 | .47* | .43* | .33* |
| RAN Letters | .19 | .31* | .10 | .35* | .35* | .14 | .16 | .13 | .17 | .28* | .23 |
| NS Composite[a] | .31* | .45* | .15 | .48* | .50* | .40* | .23 | .15 | .37 | .41* | .31* |

Note: [a]Naming Speed; [b]Reaction Time; [c]Movement Time; $^{*}p < .05$

Table 4-38

Pearson Product-Moment Correlations Among Measures of Phonological Awareness and Reaction Time

| Psychometric Test | Simple RT | Simple MT | Simple Errors | Choice RT | Choice MT | Choice Errors | OMO RT | OMO MT | OMO Errors | RT Composite[b] | MT Composite[c] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Elision | -.12 | -.21 | .07 | -.00 | -.27 | -.01 | -.18 | .23 | -.13 | -.10 | .11 |
| LAC | -.07 | -.22 | -.12 | -.18 | -.42* | -.24 | -.22 | .10 | -.31* | -.19 | -.07 |
| PA Composite[a] | -.10 | -.24 | -.03 | -.10 | -.39* | -.14 | -.22 | .19 | -.24 | -.16 | .02 |

Note: [a]Phonological Awareness; [b]Reaction Time; [c]Movement Time; * $p < .05$

Table 4-39

Pearson Product-Moment Correlations Among all Elementary Cognitive Tasks and Measures of Reading Achievement

| Elementary Cognitive Task | Letter-Word ID | Passage Comp | Word Attack | Broad Reading | Basic Reading |
|---|---|---|---|---|---|
| Visual IT | .25 | .28* | .19 | .30* | .25 |
| Simple RT | -.07 | -.13 | -.14 | -.11 | -.16 |
| Simple MT | -.32* | -.30* | -.26 | -.35* | -.31* |
| Simple Errors | -.04 | .02 | -.07 | -.06 | -.11 |
| Choice RT | -.01 | -.04 | -.08 | -.06 | -.12 |
| Choice MT | .22 | -.32* | -.18 | -.33 | -.32 |
| Choice Errors | -.09 | -.11 | -.08 | -.17 | -.18 |
| OMO RT | -.04 | -.00 | -.17 | -.04 | -.12 |
| OMO MT | -.06 | .00 | .06 | -.04 | -.02 |
| OMO Errors | -.06 | -.04 | -.09 | -.06 | -.10 |
| RT Composite[a] | -.04 | -.06 | -.15 | -.08 | -.15 |
| MT Composite[b] | -.13 | -.12 | -.03 | -.16 | -.11 |

Note: [a]Reaction Time; [b]Movement Time

Multiple Regression Analyses

Processing Speed. A significant relation was found between naming speed and processing speed in the correlation analyses. In addition, a significant relation was found between processing speed and reading achievement. Therefore, the variables that were chosen previously as independent variables in a series of simultaneous multiple

regression analyses were analyzed again, with the inclusion of the RT Composite score in each of the models. In addition, because several significant relationships were found in the correlation analyses involving MT, a fourth model was added to the analyses to investigate these relationships further. It is also important to note that although Visual IT significantly correlated with RAN Colors, a significant relationship was not found with the other two naming speed tasks. Therefore, it was not included in these analyses. For each measure of reading achievement, four different models were used (models 3a, 3b, 3c, and 3d) to investigate the relationship between naming speed, phonological awareness, processing speed, and reading achievement. In addition to these variables, age and SES was entered and controlled for in each analysis, based on the significant relationship that was found between age, SES, and these variables in previous analyses. Tables 4-40 to 4-44 present the results from the multiple regression analyses.

As can be seen from Table 4-40, all four models are statistically significant. The best model is 3d, where the five variables in combination account for 24% of the variance in the Letter-Word ID score ($F = 3.990$, $df = 47$, $p < .05$). Both phonological awareness and naming speed have a significant effect in the overall model, with the PA composite score being only a slightly better predictor of overall performance ($\beta = .384$, $p < .05$).

As can be seen from Table 4-41, all four models are statistically significant. The best model is 3d, where the five variables in combination account for 20% of the variance in the Passage Comp score ($F = 3.334$, $df = 47$, $p < .05$). The PA composite score remains the only variable with a significant effect in the overall model ($\beta = .417$, $p < .05$).

As can be seen from Table 4-42, all four models are statistically significant. The best model is 3c, where the five variables in combination account for 36% of the variance in the Word Attack score ($F = 6.607$, $df = 50$, $p < .05$). Both the PA composite score and RAN Letters task have a significant effect in the overall model, with the PA composite score being the strongest predictor of overall performance ($\beta = .514$, $p < .05$).

As can be seen from Table 4-43, all four models are statistically significant. The best model is 3d, where the five variables in combination account for 33% of the variance in the Broad Reading Skills score ($F = 5.658$, $df = 47$, $p < .05$). Both the PA composite score and the RAN Letters task have a significant effect in the overall model, with the PA composite score being a slightly better predictor of overall performance ($\beta = .448$, $p < .05$).

As can be seen from Table 4-44, all four models are statistically significant. The best model is 3d, where the five variables in combination account for 36% of the variance in the Basic Reading Skills score ($F = 6.364$, $df = 47$, $p < .05$). Both the PA composite score and the RAN Letters task have a significant effect in the overall model, with the PA composite score being a slightly better predictor of overall performance ($\beta = .482$, $p < .05$).

As can be seen from the results of the multiple regression analyses, for each of the measures of reading achievement, when the composite scores were added to each model, both naming speed and phonological awareness remained significant predictors, however the overall strength of the models dramatically decreased. In the next section, the relationship between cognitive ability and processing speed will be investigated further and included in each model.

Table 4-40

Simultaneous Multiple Regression of Naming Speed, Phonological Awareness, and Reaction Time on Letter-Word Identification

| Model | Variables | $R^2$ | Adjusted $R^2$ | *b* | $\beta$ | *t* | *p* |
|---|---|---|---|---|---|---|---|
| 3a | Age | .24* | .15* | -.891 | -.061 | -.399 | .69 |
| | SES | | | .123 | .091 | .656 | .52 |
| | RT Composite[b] | | | 1.488 | .081 | .536 | .60 |
| | Elision | | | 1.003 | .296 | 1.993 | .05 |
| | RAN Letters | | | -.631 | -.314 | -2.061* | .04 |
| 3b | Age | .27* | .18* | -1.390 | -.095 | -.630 | .53 |
| | SES | | | -.030 | -.023 | -.161 | .87 |
| | RT Composite[b] | | | 3.174 | .173 | 1.093 | .28 |
| | Elision | | | 1.070 | .315 | 2.257* | .03 |
| | RAN Numbers | | | -.812 | -.385 | -2.493* | .02 |
| 3c | Age | .26* | .18* | -1.500 | -.102 | -.669 | .51 |
| | SES | | | .101 | .075 | .547 | .59 |
| | RT Composite[b] | | | 1.669 | .091 | .615 | .54 |
| | PA Composite[a] | | | 5.627 | .338 | 2.359* | .02 |
| | RAN Letters | | | -.670 | -.334 | -2.312* | .03 |
| 3d | Age | .32* | .24* | -1.133 | -.080 | -.576 | .57 |
| | SES | | | -.011 | -.009 | -.069 | .95 |
| | MT Composite[c] | | | -2.623 | -.154 | -1.241 | .22 |
| | PA Composite[a] | | | 6.252 | .384 | 2.707* | .01 |
| | RAN Letters | | | -.611 | -.322 | -2.224* | .03 |

Note: [a]Phonological Awareness; [b]Reaction Time; [c]Movement Time; * $p < .05$

Table 4-41

Simultaneous Multiple Regression of Naming Speed, Phonological Awareness, and Reaction Time on Passage Comprehension

| Model | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| 3a | Age | .25* | .16* | -3.724 | -.282 | -1.858 | .07 |
| | SES | | | .077 | .064 | .460 | .65 |
| | RT Composite[b] | | | -2.091 | -.126 | -.839 | .41 |
| | Elision | | | 1.124 | .367 | 2.487* | .02 |
| | RAN Letters | | | -.396 | -.218 | -1.439 | .16 |
| 3b | Age | .27* | .18* | -4.058 | -.307 | -2.034 | .05 |
| | SES | | | -.022 | -.018 | -.128 | .90 |
| | RT Composite[b] | | | -.953 | -.058 | -.363 | .72 |
| | Elision | | | 1.157 | .377 | 2.698* | .01 |
| | RAN Numbers | | | -.532 | -.279 | -1.804 | .08 |
| 3c | Age | .26* | .18* | -4.257 | -.322 | -2.097 | .04 |
| | SES | | | .053 | .044 | .318 | .75 |
| | RT Composite[b] | | | -1.819 | -.110 | -.740 | .46 |
| | PA Composite[a] | | | 5.723 | .380 | 2.651* | .01 |
| | RAN Letters | | | -.460 | -.253 | -1.754 | .09 |
| 3d | Age | .28* | .20* | -3.538 | -.265 | -1.844 | .07 |
| | SES | | | -.013 | -.011 | -.075 | .94 |
| | MT Composite[c] | | | -2.118 | -.133 | -.947 | .35 |
| | PA Composite[a] | | | 6.434 | .417 | 2.858* | .01 |
| | RAN Letters | | | -.417 | -.232 | -1.557 | .13 |

Note: [a]Phonological Awareness; [b]Reaction Time; [c]Movement Time; $^{*}p < .05$

Table 4-42

Simultaneous Multiple Regression of Naming Speed, Phonological Awareness, and Reaction Time on Word Attack

| Model | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| 3a | Age | .38* | .31* | -5.411 | -.359 | -2.638* | .01 |
| | SES | | | .120 | .088 | .706 | .48 |
| | RT Composite[b] | | | -3.292 | -.174 | -1.291 | .203 |
| | Elision | | | 1.631 | .469 | 3.533* | .00 |
| | RAN Letters | | | -.511 | -.247 | -1.815 | .08 |
| 3b | Age | .40* | .33* | -5.812 | -.386 | -2.853* | .01 |
| | SES | | | -.001 | -.001 | -.004 | .99 |
| | RT Composite[b] | | | -1.944 | -.103 | -.726 | .47 |
| | Elision | | | 1.683 | .483 | 3.848* | .00 |
| | RAN Numbers | | | -.655 | -.302 | -2.180* | .03 |
| 3c | Age | .42* | .36* | -6.308 | -.419 | -3.124* | .00 |
| | SES | | | .088 | .064 | .536 | .59 |
| | RT Composite[b] | | | -2.966 | -.157 | -1.214 | .23 |
| | PA Composite[a] | | | 8.781 | .514 | 4.101* | .00 |
| | RAN Letters | | | -.587 | -.284 | -2.247* | .03 |
| 3d | Age | .41* | .34* | -4.932 | -.328 | -2.535* | .02 |
| | SES | | | .042 | .031 | .249 | .80 |
| | MT Composite[c] | | | -.311 | -.017 | -.138 | .89 |
| | PA Composite[a] | | | 8.307 | .480 | 3.657* | .00 |
| | RAN Letters | | | -.664 | -.328 | -2.444* | .02 |

Note: [a]Phonological Awareness; [b]Reaction Time; [c]Movement Time; $^*p < .05$

Table 4-43

Simultaneous Multiple Regression of Naming Speed, Phonological Awareness, and Reaction Time on Broad Reading Skills

| Model | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| 3a | Age | .29* | .21* | -1.164 | -.093 | -.629 | .53 |
| | SES | | | .121 | .105 | .781 | .44 |
| | RT Composite[b] | | | -.033 | -.002 | -.014 | .99 |
| | Elision | | | .987 | .338 | 2.367* | .02 |
| | RAN Letters | | | -.583 | -.337 | -2.297* | .03 |
| 3b | Age | .32* | .24* | -1.604 | -.127 | -.877 | .39 |
| | SES | | | -.017 | -.015 | -.109 | .91 |
| | RT Composite[b] | | | 1.442 | .092 | .599 | .55 |
| | Elision | | | 1.059 | .363 | 2.694* | .01 |
| | RAN Numbers | | | -.727 | -.401 | -2.692* | .01 |
| 3c | Age | .33* | .25* | -1.794 | -.143 | -.976 | .34 |
| | SES | | | .099 | .086 | .658 | .514 |
| | RT Composite[b] | | | .131 | .008 | .059 | .95 |
| | PA Composite[a] | | | 5.654 | .395 | 2.892* | .01 |
| | RAN Letters | | | -.617 | -.357 | -2.598* | .01 |
| 3d | Age | .40* | .33* | -1.317 | -.106 | -.809 | .42 |
| | SES | | | .045 | .040 | .311 | .76 |
| | MT Composite[c] | | | -1.863 | -.126 | -.982 | .33 |
| | PA Composite[a] | | | 6.429 | .448 | 3.367* | .00 |
| | RAN Letters | | | -.556 | -.333 | -2.447* | .02 |

Note: [a]Phonological Awareness; [b]Reaction Time; [c]Movement Time; *$p < .05$

Table 4-44

Simultaneous Multiple Regression of Naming Speed, Phonological Awareness, and Reaction Time on Basic Reading Skills

| Model | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| 3a | Age | .34* | .26* | -2.398 | -.162 | -1.137 | .262 |
| | SES | | | .117 | .086 | .659 | .51 |
| | RT Composite[b] | | | -1.463 | -.079 | -.558 | .58 |
| | Elision | | | 1.426 | .415 | 2.999* | .00 |
| | RAN Letters | | | -.612 | -.300 | -2.114* | .04 |
| 3b | Age | .35* | .28* | -2.837 | -.191 | -1.351 | .18 |
| | SES | | | -.025 | -.018 | -.140 | .89 |
| | RT Composite[b] | | | -.002 | .000 | -.001 | 1.00 |
| | Elision | | | 1.511 | .440 | 3.348* | .00 |
| | RAN Numbers | | | -.739 | -.346 | -2.382* | .02 |
| 3c | Age | .38* | .31* | -3.249 | -.219 | -1.563 | .13 |
| | SES | | | .085 | .063 | .500 | .62 |
| | RT Composite[b] | | | -1.199 | -.065 | -.477 | .64 |
| | PA Composite[a] | | | 7.941 | .470 | 3.592* | .00 |
| | RAN Letters | | | -.669 | -.329 | -2.491* | .02 |
| 3d | Age | .43* | .36* | -2.140 | -.148 | -1.154 | .26 |
| | SES | | | .024 | .018 | .148 | .88 |
| | MT Composite[c] | | | -1.287 | -.074 | -.595 | .56 |
| | PA Composite[a] | | | 8.070 | .482 | 3.709* | .00 |
| | RAN Letters | | | -.678 | -.348 | -2.619* | .01 |

Note: [a]Phonological Awareness; [b]Reaction Time; [c]Movement Time; $^*p < .05$

Psychometric Comparisons

Cognitive Ability and Processing Speed. Table 4-45 presents correlations among BCA and the ECT variables. As can be seen from the table, a significant relation was found between several of the MT variables and BCA (all $ps < .05$).

Table 4-45

Pearson Product-Moment Correlations Among Elementary Cognitive Tasks and Cognitive Ability

| Elementary Cognitive Task | BCA |
|---|---|
| Visual IT | -.10 |
| Simple RT | -.18 |
| Simple MT | -.55* |
| Simple Errors | .07 |
| Choice RT | -.06 |
| Choice MT | -.52* |
| Choice Errors | -.13 |
| OMO RT | -.13 |
| OMO MT | -.25 |
| OMO Errors | -.08 |
| RT Composite[a] | -.14 |
| MT Composite[b] | -.41* |

Note: [a]Reaction Time; [b]Movement Time; *$p < .05$

Multiple Regression Analyses

Cognitive Ability and Processing Speed. Based on the results of the correlation analyses, a significant relation was found between naming speed, phonological awareness, cognitive ability, and processing speed. Therefore, all of the variables that were chosen previously as independent variables were combined in a series of simultaneous multiple regression analyses. For each measure of reading achievement, four different models were used (models 4a, 4b, 4c, and 4d) to investigate the relationsbip between naming speed, phonological awareness, cognitive ability, processing speed, and reading achievement. In addition to these variables, age and SES was entered and controlled for in each analysis, based on the significant relationship that was found between age, SES, and these variables in previous analyses. Tables 4-46 to 4-50 present the results from these analyses.

As can be seen from Table 4-46, all four models are statistically significant. The best model is 4d, where the six variables in combination account for 24% of the variance in the Letter-Word ID score ($F = 3.409$, $df = 45$, $p < .05$). The PA composite score remains the only variable with a significant effect in the overall model ($\beta = .400$, $p < .05$).

As can be seen from Table 4-47, all four models are statistically significant. The best model is 4b, where the six variables in combination account for 33% of the variance in the Passage Comp score ($F = 4.765$, $df = 47$, $p < .05$). BCA emerges as the strongest predictor of overall performance ($\beta = .453$, $p < .05$), with the Elision having only significantly minimal effects.

As can be seen from Table 4-48, all four models are statistically significant. The best model is 4c, where the six variables in combination account for 35% of the variance

in the Word Attack score ($F = 5.210$, $df = 48$, $p < .05$). The PA composite score remains the only predictor with a significant effect ($\beta = .445$, $p < .05$). Age also has a significant effect in the overall model ($\beta = -.391$, $p < .05$).

As can be seen from Table 4-49, all four models are statistically significant. The best model is 4d, where the six variables in combination account for 36% of the variance in the Broad Reading Skills score ($F = 5.155$, $df = 45$, $p < .05$). The PA composite score remains the only variable with a significant effect in the overall model ($\beta = .355$, $p < .05$).

As can be seen from Table 4-50, all four models are statistically significant. The best model is 4d, where the six variables in combination account for 34% of the variance in the Basic Reading Skills score ($F = 4.896$, $df = 45$, $p < .05$). Both the PA composite score and RAN Letters showed significant effects, with the PA composite score being a slightly stronger predictor of overall performance ($\beta = .463$, $p < .05$).

<u>Summary of Analyses</u>

Table 4-51 presents a summary of the best (i.e., most predictive) multiple regression model for each reading measure based on the adjusted $R^2$ values for each model. It is interesting to note that for three of the reading measures (i.e., Passage Comp, Word Attack, and Basic Reading) two models were the most predictive. As can also be seen from the table, the best prediction models for most of the reading measures include BCA. It is interesting that, on average, the strength of these models decrease ($\Delta$ adjusted $R^2 = .13$) when BCA is not included. It is also important to note that the inclusion of processing speed dramatically reduced the strength of these models. On average, the $\Delta$ adjusted $R^2 = -.19$ when processing speed variables are included. These results will be discussed in greater detail in Chapter 5.

Table 4-46

Simultaneous Multiple Regression of Naming Speed, Phonological Awareness, Cognitive Ability, and Reaction Time on Letter-Word Identification

| Model | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| 4a | Age | .32* | .22* | -.942 | -.064 | -.422 | .68 |
| | SES | | | .108 | .080 | .573 | .57 |
| | BCA | | | .336 | .269 | 1.888 | .07 |
| | RT Composite[b] | | | 1.993 | .110 | .738 | .47 |
| | Elision | | | .968 | .287 | 1.932 | .06 |
| | RAN Letters | | | -.446 | -.223 | -1.424 | .16 |
| 4b | Age | .33* | .23* | -1.184 | -.081 | -.531 | .60 |
| | SES | | | -.001 | -.001 | -.004 | 1.00 |
| | BCA | | | .302 | .241 | 1.671 | .10 |
| | RT Composite[b] | | | 3.168 | .175 | 1.109 | .27 |
| | Elision | | | 1.023 | .303 | 2.112* | .04 |
| | RAN Numbers | | | -.569 | -.274 | -1.667 | .10 |
| 4c | Age | .32* | .22* | -1.303 | -.089 | -.572 | .57 |
| | SES | | | -.096 | .071 | .512 | .61 |
| | BCA | | | .267 | .214 | 1.431 | .16 |
| | RT Composite[b] | | | 2.261 | .125 | .844 | .40 |
| | PA Composite[a] | | | 4.891 | .297 | 1.946 | .06 |
| | RAN Letters | | | -.538 | -.269 | -1.775 | .08 |
| 4d | Age | .34* | .24* | -1.237 | -.088 | -.601 | .55 |
| | SES | | | .088 | .069 | .500 | .62 |
| | BCA | | | .089 | .074 | .436 | .66 |
| | MT Composite[c] | | | -1.365 | -.082 | -.523 | .60 |
| | PA Composite[a] | | | 6.405 | .400 | 2.463* | .02 |
| | RAN Letters | | | -.542 | -.288 | -1.891 | .07 |

Note: [a]Phonological Awareness; [b]Reaction Time; [c]Movement Time; *$p < .05$

Table 4-47

Simultaneous Multiple Regression of Naming Speed, Phonological Awareness, Cognitive Ability, and Reaction Time on Passage Comprehension

| Model | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| 4a | Age | .41* | .32* | -3.820 | -.287 | -2.027 | .05 |
| | SES | | | -.037 | -.030 | -.235 | .82 |
| | BCA | | | .529 | .466 | 3.524* | .00 |
| | RT Composite[b] | | | -2.122 | -.129 | -.932 | .36 |
| | Elision | | | .850 | .277 | 2.011 | .05 |
| | RAN Letters | | | -.137 | -.075 | -.517 | .61 |
| 4b | Age | .41* | .33* | -3.918 | -.294 | -2.070 | .05 |
| | SES | | | -.073 | -.060 | -.459 | .65 |
| | BCA | | | .514 | .453 | 3.351* | .00 |
| | RT Composite[b] | | | -1.686 | -.102 | -.695 | .49 |
| | Elision | | | .860 | .281 | 2.093* | .04 |
| | RAN Numbers | | | -.198 | -.105 | -.683 | .50 |
| 4c | Age | .38* | .29* | -3.868 | -.290 | -1.971 | .06 |
| | SES | | | -.054 | -.044 | -.336 | .74 |
| | BCA | | | .495 | .436 | 3.078* | .00 |
| | RT Composite[b] | | | -1.773 | -.108 | -.768 | .45 |
| | PA Composite[a] | | | 3.262 | .219 | 1.507 | .139 |
| | RAN Letters | | | -.234 | -.129 | -.898 | .38 |
| 4d | Age | .38* | .28* | -2.902 | -.215 | -1.519 | .14 |
| | SES | | | -.062 | -.051 | -.376 | .71 |
| | BCA | | | .517 | .450 | 2.729* | .01 |
| | MT Composite[c] | | | 1.030 | .065 | .425 | .67 |
| | PA Composite[a] | | | 3.403 | .223 | 1.409 | .17 |
| | RAN Letters | | | -.263 | -.147 | -.989 | .33 |

Note: [a]Phonological Awareness; [b]Reaction Time; [c]Movement Time; *$p < .05$

Table 4-48

Simultaneous Multiple Regression of Naming Speed, Phonological Awareness, Cognitive Ability, and Reaction Time on Word Attack

| Model | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| 4a | Age | .42* | .34* | -5.290 | -.352 | -2.538* | .02 |
| | SES | | | .043 | .031 | .247 | .81 |
| | BCA | | | .375 | .293 | 2.262* | .03 |
| | RT Composite[b] | | | -3.142 | -.169 | -1.248 | .22 |
| | Elision | | | 1.436 | .417 | 3.076* | .00 |
| | RAN Letters | | | -.307 | -.150 | -1.049 | .30 |
| 4b | Age | .43* | .34* | -5.478 | -.365 | -2.629* | .01 |
| | SES | | | -.033 | -.024 | -.188 | .85 |
| | BCA | | | .347 | .271 | 2.054 | .05 |
| | RT Composite[b] | | | -2.266 | -.122 | -.849 | .40 |
| | Elision | | | 1.467 | .426 | 3.242* | .00 |
| | RAN Numbers | | | -.413 | -.194 | -1.297 | .20 |
| 4c | Age | .43* | .35* | -5.877 | -.391 | -2.785* | .01 |
| | SES | | | .028 | .021 | .163 | .87 |
| | BCA | | | .268 | .209 | 1.549 | .13 |
| | RT Composite[b] | | | -2.770 | -.149 | -1.116 | .27 |
| | PA Composite[a] | | | 7.447 | .445 | 3.205* | .00 |
| | RAN Letters | | | -.440 | -.215 | -1.566 | .13 |
| 4d | Age | .40* | .31* | -4.309 | -.287 | -2.088* | .04 |
| | SES | | | .008 | .006 | .048 | .96 |
| | BCA | | | .265 | .208 | 1.293 | .20 |
| | MT Composite[c] | | | 1.397 | .079 | .536 | .60 |
| | PA Composite[a] | | | 6.721 | .398 | 2.587* | .01 |
| | RAN Letters | | | 1.397 | .079 | .536 | .60 |

Note: [a]Phonological Awareness; [b]Reaction Time; [c]Movement Time; *$p < .05$

Table 4-49

Simultaneous Multiple Regression of Naming Speed, Phonological Awareness, Cognitive Ability, and Reaction Time on Broad Reading Skills

| Model | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| 4a | Age | .42* | .33* | -1.243 | -.097 | -.694 | .49 |
| | SES | | | .056 | .048 | .373 | .71 |
| | BCA | | | .433 | .399 | 3.038* | .00 |
| | RT Composite[b] | | | .201 | .013 | .093 | .93 |
| | Elision | | | .832 | .283 | 2.072 | .05 |
| | RAN Letters | | | -.361 | -.207 | -1.436 | .16 |
| 4b | Age | .42* | .34* | -1.417 | -.111 | -.790 | .43 |
| | SES | | | -.029 | -.025 | -.192 | .85 |
| | BCA | | | .410 | .377 | 2.823* | .01 |
| | RT Composite[b] | | | 1.076 | .068 | .468 | .64 |
| | Elision | | | .883 | .301 | 2.266* | .03 |
| | RAN Numbers | | | -4.36 | -.241 | -1.590 | .12 |
| 4c | Age | .42* | .33* | -1.523 | -.119 | -.831 | .41 |
| | SES | | | .045 | .039 | .301 | .77 |
| | BCA | | | .377 | .347 | 2.513* | .02 |
| | RT Composite[b] | | | .445 | .028 | .206 | .84 |
| | PA Composite[a] | | | 4.084 | .286 | 2.021 | .05 |
| | RAN Letters | | | -.442 | -.254 | -1.813 | .08 |
| 4d | Age | .44* | .36* | -1.091 | -.087 | -.644 | .52 |
| | SES | | | .038 | .033 | .260 | .80 |
| | BCA | | | .291 | .272 | 1.737 | .09 |
| | MT Composite[c] | | | -.357 | -.024 | -.166 | .87 |
| | PA Composite[a] | | | 5.070 | .355 | 2.369* | .02 |
| | RAN Letters | | | -.450 | -.268 | -1.907 | .06 |

Note: [a]Phonological Awareness; [b]Reaction Time; [c]Movement Time; *$p < .05$

Table 4-50

Simultaneous Multiple Regression of Naming Speed, Phonological Awareness, Cognitive Ability, and Reaction Time on Basic Reading Skills

| Model | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| 4a | Age | .39* | .30* | -2.325 | -.156 | -1.086 | .284 |
| | SES | | | .066 | .048 | .368 | .72 |
| | BCA | | | .358 | .282 | 2.100* | .04 |
| | RT Composite[b] | | | -1.109 | -.060 | -.429 | .67 |
| | Elision | | | 1.307 | .381 | 2.724* | .01 |
| | RAN Letters | | | -.412 | -.203 | -1.373 | .177 |
| 4b | Age | .40* | .31* | -2.513 | -.168 | -1.171 | .25 |
| | SES | | | -.030 | -.022 | -.165 | .87 |
| | BCA | | | .333 | .263 | 1.917 | .06 |
| | RT Composite[b] | | | -.142 | -.008 | -.052 | .96 |
| | Elision | | | 1.368 | .399 | 2.933* | .01 |
| | RAN Numbers | | | -.489 | -.231 | -1.487 | .15 |
| 4c | Age | .40* | .32* | -2.904 | -.195 | -1.344 | .19 |
| | SES | | | .053 | .038 | .296 | .77 |
| | BCA | | | .256 | .202 | 1.448 | .16 |
| | RT Composite[b] | | | -.785 | -.043 | -.309 | .76 |
| | PA Composite[a] | | | 6.952 | .416 | 2.917* | .01 |
| | RAN Letters | | | -.531 | -.261 | -1.846 | .07 |
| 4d | Age | .43* | .34* | -1.885 | -.129 | -.952 | .35 |
| | SES | | | .026 | .020 | .154 | .88 |
| | BCA | | | .122 | .098 | .623 | .54 |
| | MT Composite[c] | | | -.712 | -.041 | -.283 | .78 |
| | PA Composite[a] | | | 7.646 | .463 | 3.056* | .00 |
| | RAN Letters | | | -.596 | -.307 | -2.160* | .04 |

Note: [a]Phonological Awareness; [b]Reaction Time; [c]Movement Time; * $p < .05$

Table 4-51

Summary of the Best Prediction Models for Each Measure of Reading Achievement

| Model | Reading Measure | Predictor Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|---|
| 2b | Letter-Word ID | Age | .33* | .27* | -3.415 | -.226 | -1.707 | .10 |
| | | BCA | | | .291 | .219 | 1.588 | .12 |
| | | Elision | | | 1.235 | .346 | 2.593* | .01 |
| | | RAN Numbers | | | -.540 | -.245 | -1.710 | .09 |
| 2a | Passage Comp | Age | .41* | .36* | -3.786 | -.283 | -2.317* | .03 |
| | | BCA | | | .510 | .434 | 3.466* | .00 |
| | | Elision | | | .878 | .278 | 2.130* | .04 |
| | | RAN Letters | | | -.245 | -.131 | -.968 | .34 |
| 2b | Passage Comp | Age | .42* | .36* | -3.997 | -.299 | -2.422* | .02 |
| | | BCA | | | .482 | .410 | 3.181* | .00 |
| | | Elision | | | .937 | .296 | 2.384* | .02 |
| | | RAN Numbers | | | -.315 | -.162 | -1.211 | .23 |
| 1b | Word Attack | Age | .42* | .39* | -5.857 | -.385 | -3.327* | .00 |
| | | Elision | | | 1.686 | .467 | 4.039* | .00 |
| | | RAN Numbers | | | -.775 | -.345 | -2.923* | .01 |
| 2b | Word Attack | Age | .44* | .39* | -5.545 | -.365 | -3.056* | .00 |
| | | BCA | | | .313 | .234 | 1.881 | .07 |
| | | Elision | | | 1.517 | .423 | 3.520* | .00 |
| | | RAN Numbers | | | -.568 | -.257 | -1.986 | .05 |
| 2b | Broad Reading | Age | .43* | .37* | -2.879 | -.218 | -1.783 | .08 |
| | | BCA | | | .387 | .334 | 2.616* | .01 |
| | | Elision | | | 1.052 | .337 | 2.735* | .01 |
| | | RAN Numbers | | | -.483 | -.251 | -1.898 | .06 |

Table 4-51-continued

| Model | Reading Measure | Predictor Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|---|
| 2b | Basic Reading | Age | .41* | .36* | -3.534 | -.232 | -1.876 | .07 |
| | | BCA | | | .305 | .228 | 1.767 | .08 |
| | | Elision | | | 1.500 | .417 | 3.345* | .00 |
| | | RAN Numbers | | | -.580 | -.262 | -1.954 | .06 |
| 3d | Basic Reading | Age | .43* | .36* | -2.140 | -.148 | -1.154 | .26 |
| | | SES | | | .024 | .018 | .148 | .88 |
| | | MT Composite[a] | | | -1.287 | -.074 | -.595 | .56 |
| | | PA Composite[b] | | | 8.070 | .482 | 3.709* | .00 |
| | | RAN Letters | | | -.678 | -.348 | -2.619* | .01 |

Note: $^*p < .05$; [a]Movement Time; [b]Phonological Awareness

## Research Question 3

What is the relationship between neuroanatomy and specific predictors of reading, such as naming speed? This hypothesis was investigated through the use of correlation and simultaneous multiple regression analyses.

Before correlations were conducted among the psychometric tests, ECTs, and specific neuroanatomical regions, the relationship between total brain volume (Total BV) and the specific neuroanatomical regions was investigated. Therefore, if a significant relationship was found between any of the specific neuroanatomical regions and Total BV, it would be controlled for in any of the multiple regression analyses that followed. Table 4-52 presents correlations among all of the specific neuroanatomical regions and

Total BV. As can be seen from the table, many significant relations with Total BV were found.

It is also important to note that if any significant relationships were found among the neuroanatomical regions and any of the other control variables (i.e., age, sex, handedness, SES) in previous analyses, they were also included in the regression models.

Naming Speed

Table 4-53 presents correlations among the naming speed tasks and specific neuroanatomical regions measured in this study. As can be seen from the table, several significant correlations were found for the RAN Colors and RAN Letters tasks. Specifically, a significant relation was found between the size of the left and right parietale and performance on the RAN Colors task ($r = -.29$, $p < .05$). In addition, a significant relation was found between both total brain asymmetry ($r = -.31$, $p < .05$) and the size of the rostrum of the corpus callosum ($r = .35$, $p < .05$) with performance on the RAN Letters task. Because multiple neuroanatomical regions were significantly related to performance, these relationships were investigated further using simultaneous multiple regression analyses. The results of those analyses are displayed in Table 4-54.

As can be seen from Table 4-54, both models are statistically significant. For model a, the variables together account for 9% of the overall variance in the RAN Colors score, however none emerge as significant predictors. In model b, the variables together account for 15% of the overall variance in the RAN Letters score ($F = 3.228$; $df = 51$, $p < .05$). Both total brain asymmetry and the rostrum emerge as significant predictors of overall performance, with the rostrum being a slightly stronger predictor ($\beta = .366$, $p < .05$).

Table 4-52

Pearson Product-Moment Correlations Among Neuroanatomical Regions and Total Brain Volume

| Neuroanatomical Region | $r$ | $p$ |
|---|---|---|
| Left PT | .16 | .23 |
| Right PT | .24 | .07 |
| Asym PT | -.08 | .57 |
| Left Planum | .17 | .20 |
| Right Planum | .13 | .35 |
| Planar Asym | -.02 | .88 |
| Left Parietale | .15 | .27 |
| Right Parietale | .14 | .32 |
| Parietale Asym | .05 | .71 |
| Left H1 | .27* | .04 |
| Right H1 | .22 | .10 |
| Left H2 | -.07 | .63 |
| Right H2 | .14 | .31 |
| Rostrum | .30* | .02 |
| Genu | .42* | .00 |
| Body | .60* | .00 |
| Isthmus | .16 | .25 |
| Splenium | .33* | .01 |
| Total CC | .54* | .00 |
| Left Ant Lobe | .50* | .00 |
| Right Ant Lobe | .28* | .04 |
| Total Ant Lobe | .41* | .00 |
| Asym Ant Lobe | .26 | .05 |

Note: $^{*}p < .05$

Table 4-53

Pearson Product-Moment Correlations Among Measures of Naming Speed and Specific Neuroanatomical Regions

| Neuroanatomical Region | RAN Colors | RAN Numbers | RAN Letters | NS Composite[a] |
|---|---|---|---|---|
| Left BV | -.07 | -.16 | -.06 | -.12 |
| Right BV | -.01 | -.10 | .06 | -.02 |
| Total BV | -.04 | -.13 | .00 | -.07 |
| Asym BV | -.16 | -.16 | -.31* | -.25 |
| Left PT | -.05 | -.04 | -.02 | -.07 |
| Right PT | -.16 | -.06 | -.07 | -.16 |
| Asym PT | .11 | .01 | .07 | .10 |
| Left Planum | .02 | .06 | .09 | .07 |
| Right Planum | .11 | .23 | .21 | .23 |
| Planar Asym | -.08 | -.11 | -.08 | -.12 |
| Left Parietale | -.29* | -.21 | -.16 | -.24 |
| Right Parietale | -.29* | -.17 | -.08 | -.19 |
| Parietale Asym | -.15 | -.08 | -.10 | -.15 |
| Left H1 | -.20 | -.06 | -.09 | -.17 |
| Right H1 | -.12 | .06 | .12 | -.01 |
| Left H2 | .15 | .03 | -.02 | .06 |
| Right H2 | .11 | -.07 | -.16 | -.03 |
| Rostrum | .16 | .20 | .35* | .23 |
| Genu | -.19 | -.22 | -.06 | -.19 |
| Body | -.13 | -.17 | .01 | -.15 |
| Isthmus | -.19 | -.24 | -.13 | -.22 |
| Splenium | -.13 | -.20 | -.10 | -.20 |
| Total CC | -.14 | -.20 | .00 | -.17 |
| Left Ant Lobe | .09 | .02 | .19 | .11 |
| Right Ant Lobe | .15 | -.05 | .14 | .08 |
| Total Ant Lobe | .13 | -.02 | .18 | .10 |
| Asym Ant Lobe | -.16 | .03 | -.01 | -.04 |

Note: [a]Naming Speed; * $p < .05$

Table 4-54

Simultaneous Multiple Regression of the Neuroanatomical Regions on Naming Speed

| Model[a] | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| a | Left Parietale | .13* | .09* | -1.943 | -.224 | -1.640 | .11 |
| | Right Parietale | | | -2.155 | -.215 | -1.570 | .12 |
| b | Sex | .22* | .15* | 1.490 | .107 | .724 | .47 |
| | Total BV | | | -.004 | -.050 | -.341 | .74 |
| | Asym BV | | | -64.569 | -.278 | -2.138* | .04 |
| | Rostrum | | | 22.103 | .364 | 2.658* | .01 |

Note: *$p < .05$; [a]Dependent variables: a = RAN Colors, b = RAN Letters

Phonological Awareness

Table 4-55 presents correlations among the phonological awareness tasks and specific neuroanatomical regions measured in this study. As can be seen from the table, significant correlations were found for the left and right parietale. More specifically, between the left parietale and the Elision task ($r = .30, p < .05$), the right parietale and the LAC ($r = .27, p < .05$), and the left parietale and the PA composite score ($r = .32, p < .05$). Because multiple regions did not predict each task, and these regions did not correlate with age, sex, handedness, SES, or total brain volume in previous analyses, further multiple regression analyses were not conducted.

Cognitive Ability

Table 4-56 presents correlations among BCA and the specific neuroanatomical regions measured in this study. As can be seen in the table, no significant relations were found.

Table 4-55

Pearson Product-Moment Correlations Among Measures of Phonological Awareness and Neuroanatomical Regions

| Neuroanatomical Region | Elision | LAC | PA Composite[a] |
|---|---|---|---|
| Left BV | .00 | .15 | .09 |
| Right BV | .02 | .20 | .13 |
| Total BV | .01 | .18 | .11 |
| Asym BV | -.05 | -.12 | -.10 |
| Left PT | .02 | .05 | .04 |
| Right PT | -.07 | .02 | -.03 |
| Asym PT | .06 | .02 | .05 |
| Left Planum | -.17 | .06 | -.06 |
| Right Planum | -.24 | .02 | -.12 |
| Planar Asym | .09 | .01 | .06 |
| Left Parietale | .30* | .26 | .32* |
| Right Parietale | .13 | .27* | .23 |
| Parietale Asym | .10 | -.06 | .02 |
| Left H1 | .13 | .08 | .12 |
| Right H1 | -.02 | .19 | .10 |
| Left H2 | -.07 | -.21 | -.16 |
| Right H2 | -.08 | -.12 | -.12 |
| Rostrum | -.24 | .07 | -.10 |
| Genu | -.17 | -.11 | -.16 |
| Body | -.13 | .10 | -.02 |
| Isthmus | -.05 | .05 | -.00 |
| Splenium | -.04 | .03 | .00 |
| Total CC | -.14 | .04 | -.06 |
| Left Ant Lobe | -.20 | -.03 | -.13 |
| Right Ant Lobe | -.12 | -.00 | -.07 |
| Total Ant Lobe | -.17 | -.04 | -.10 |
| Asym Ant Lobe | -.05 | -.01 | -.05 |

Note: [a]Phonological Awareness; *$p < .05$

Table 4-56

Pearson Product-Moment Correlations Among Cognitive Ability and Neuroanatomical Regions

| Neuroanatomical Region | BCA |
|---|---|
| Left BV | .22 |
| Right BV | .23 |
| TBV | .23 |
| Asym BV | -.03 |
| Left PT | .06 |
| Right PT | .08 |
| Asym PT | -.01 |
| Left Planum | .01 |
| Right Planum | -.16 |
| Planar Asym | .08 |
| Left Parietale | .27 |
| Right Parietale | .20 |
| Parietale Asym | -.03 |
| Left H1 | .02 |
| Right H1 | -.01 |
| Left H2 | -.05 |
| Right H2 | .08 |
| Rostrum | -.01 |
| Genu | -.04 |
| Body | .17 |
| Isthmus | .23 |
| Splenium | .09 |
| Total CC | .11 |
| Left Ant Lobe | -.10 |
| Right Ant Lobe | -.00 |
| Total Ant Lobe | -.05 |
| Asym Ant Lobe | -.10 |

Processing Speed

Visual IT. Table 4-57 presents correlations among the IT task and specific neuroanatomical regions measured in this study. As can be seen from the table, several significant relations were found for the IT task. Because multiple regions were involved, these significant relations were analyzed further using multiple regression analyses. These results are presented in Table 4-58. It should be noted that since the left planum contributes to planar asymmetry, only the left planum was included in these models. As can be seen from the table, the overall model is statistically significant ($F = 10.654$, $df = 51$, $p < .05$). The variables together account for 28% of the variance in the Visual IT score. In addition, we can see that Heschl's gyrus (Left H2) emerges as the only significant predictor in the overall model ($\beta = .446$, $p < .05$).

Reaction Time. Table 4-59 presents correlations among the RT tasks and specific neuroanatomical regions measured in this study. As can be seen from the table, several significant correlations were found between the neuroanatomical regions and the Simple RT task. Because multiple regions were involved, and because significant relations were found between brain volume and sex, these variables were analyzed further using simultaneous multiple regression. In addition, because of the high correlation between the right and left volumes of the brain with total brain volume ($r = .98$, $p < .05$), only total brain volume was used in these analyses. The results are displayed in Table 4-60. As can be seen, the overall model is statistically significant ($F = 3.064$, $df = 48$, $p < .05$), however none of the variables emerge as significant predictors of the Simple RT score.

Table 4-57

Pearson Product-Moment Correlations Among Inspection Time and Neuroanatomical Regions

| Neuroanatomical Region | Visual IT |
|---|---|
| Left BV | -.16 |
| Right BV | -.05 |
| Total BV | -.11 |
| Asym BV | -.25 |
| Left PT | .08 |
| Right PT | -.19 |
| Asym PT | .22 |
| Left Planum | -.06 |
| Right Planum | -.08 |
| Planar Asym | .01 |
| Left Parietale | -.36* |
| Right Parietale | -.06 |
| Parietale Asym | -.31* |
| Left H1 | -.27 |
| Right H1 | .00 |
| Left H2 | .52* |
| Right H2 | -.07 |
| Rostrum | -.07 |
| Genu | -.11 |
| Body | -.14 |
| Isthmus | -.03 |
| Splenium | -.08 |
| Total CC | -.13 |
| Left Ant Lobe | -.20 |
| Right Ant Lobe | .03 |
| Total Ant Lobe | -.12 |
| Asym Ant Lobe | -.24 |

Note: $^*p < .05$

Table 4-58

Simultaneous Multiple Regression of the Neuroanatomical Regions on Inspection Time

| Model[a] | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| a | Left Parietale | .30* | .28* | -7.625 | -.199 | -1.556 | .13 |
| | Left H2 | | | 16.416 | .446 | 3.482* | .00 |

Note: *$p < .05$; [a]Dependent variable: a = Inspection Time

Reading Achievement

Table 4-61 presents correlations among the measures of reading achievement and neuroanatomical regions. As can be seen from the table, significant relations were found between the right planum and scores on all of the reading measures, except for Passage Comp (all other *ps* < .05). In addition, planar asymmetry significantly correlates with all of the reading measures except for Passage Comp and Word Attack (all other *ps* < .05). Other significant correlations were found between the left anterior lobe of the cerebellum and Word Attack ($r = -.27, p < .05$) and between the right parietale and Broad Reading Skills. Because several neuroanatomical regions predicted each reading measure, these relationships were investigated further using multiple regression analyses. These results are presented in Table 4-62. It should be noted that since the right planum contributes to planar asymmetry, only the right planum was included in these models. As we can see from the table, both models are statistically significant. In model a, the variables together account for 19% of the overall variance ($F = 4.270$, $df = 55$, $p < .05$). In addition, both the left anterior lobe of the cerebellum ($\beta = -.435$, $p < .05$) and the right planum ($\beta = -.379$, $p < .05$) emerge as significant predictors of Word Attack. In model b, the variables together account for 13% of the overall variance ($F = 5.145$, $df = 54$, $p < .05$). In

addition, only the right planum ($\beta = -.320$, $p < .05$) emerges as a significant predictor of Broad Reading Skills.

Table 4-59

Pearson Product-Moment Correlations Among Reaction Time and Neuroanatomical Regions

| Neuroanatomical Region | Simple RT | Choice RT | OMO RT | RT Composite[a] | MT Composite[b] |
|---|---|---|---|---|---|
| Left BV | -.29* | .05 | -.13 | -.12 | .03 |
| Right BV | -.33* | .08 | -.12 | -.12 | -.03 |
| Total BV | -.32* | .07 | -.13 | -.12 | -.00 |
| Asym BV | .09 | -.07 | -.03 | .01 | .13 |
| Left PT | -.12 | -.15 | -.07 | -.12 | .12 |
| Right PT | -.21 | -.11 | -.05 | -.12 | .05 |
| Asym PT | .07 | -.03 | -.01 | -.01 | .06 |
| Left Planum | -.14 | -.04 | -.08 | -.09 | -.15 |
| Right Planum | .07 | -.03 | -.09 | -.02 | .10 |
| Planar Asym | -.13 | .02 | .02 | -.03 | -.16 |
| Left Parietale | -.09 | -.20 | .00 | -.10 | -.13 |
| Right Parietale | .14 | -.04 | .14 | .07 | -.09 |
| Parietale Asym | -.17 | -.18 | -.12 | -.16 | .01 |
| Left H1 | -.32* | -.23 | -.26 | -.29* | -.09 |
| Right H1 | -.17 | -.11 | -.13 | -.13 | -.09 |
| Left H2 | .06 | .14 | .15 | .13 | -.25 |
| Right H2 | -.13 | .13 | .05 | .02 | -.25 |
| Rostrum | .12 | .20 | .09 | .14 | .00 |
| Genu | -.06 | .00 | .02 | -.02 | -.12 |
| Body | -.13 | -.03 | -.06 | -.07 | -.06 |
| Isthmus | .01 | -.08 | .02 | -.04 | -.12 |
| Splenium | -.23 | -.12 | -.11 | -.17 | -.03 |
| Total CC | -.13 | -.03 | -.04 | -.08 | -.09 |
| Left Ant Lobe | -.06 | .13 | .25 | .14 | .15 |
| Right Ant Lobe | -.04 | .13 | .14 | .10 | .13 |
| Total Ant Lobe | -.06 | .14 | .20 | .13 | .15 |
| Asym Ant Lobe | -.05 | -.04 | .12 | .02 | .00 |

Note: *p < .05; [a]Reaction Time; [b]Movement Time

Table 4-60

Simultaneous Multiple Regression of the Neuroanatomical Regions on Simple Reaction Time

| Model[a] | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| a | Sex | .17* | .11* | 12.509 | .113 | .780 | .44 |
| | Total BV | | | -.142 | -.211 | -1.399 | .17 |
| | Left H1 | | | -16.896 | -.266 | -1.854 | .07 |

Note: *$p < .05$; [a]Dependent variable: a = Simple RT

Table 4-61

Pearson Product-Moment Correlations Among Measures of Reading Achievement and Neuroanatomical Regions

| Neuroanatomical Region | Letter-Word ID | Passage Comp | Word Attack | Broad Reading | Basic Reading |
|---|---|---|---|---|---|
| Left BV | -.01 | .16 | .00 | .09 | .04 |
| Right BV | -.01 | .22 | .04 | .11 | .08 |
| Total BV | -.01 | .19 | .02 | .10 | .06 |
| Asym BV | .02 | -.17 | -.10 | -.06 | -.09 |
| Left PT | .07 | .05 | -.03 | .08 | .05 |
| Right PT | .02 | .05 | .01 | .05 | .07 |
| Asym PT | .02 | -.02 | -.03 | .00 | -.05 |
| Left Planum | -.01 | -.05 | -.16 | -.00 | -.04 |
| Right Planum | -.44* | -.22 | -.36* | -.37* | -.38* |
| Planar Asym | .40* | .11 | .16 | .32* | .29* |
| Left Parietale | .10 | .16 | .22 | .13 | .23 |
| Right Parietale | .21 | .25 | .24 | .27* | .22 |
| Parietale Asym | -.22 | -.06 | -.13 | -.19 | -.11 |
| Left H1 | -.11 | .01 | -.20 | -.08 | -.09 |
| Right H1 | -.22 | -.02 | -.19 | -.15 | -.14 |
| Left H2 | .04 | .14 | .04 | .09 | .03 |
| Right H2 | -.04 | .04 | -.14 | -.02 | -.08 |
| Rostrum | .16 | .04 | -.00 | .10 | .09 |
| Genu | -.07 | -.09 | -.03 | -.07 | -.09 |
| Body | -.07 | -.00 | -.05 | -.04 | -.04 |
| Isthmus | .13 | .15 | .15 | .16 | .19 |
| Splenium | .05 | .04 | -.00 | .05 | .05 |
| Total CC | -.02 | -.00 | -.02 | -.01 | -.01 |
| Left Ant Lobe | -.17 | -.08 | -.27* | -.13 | -.17 |
| Right Ant Lobe | -.02 | -.04 | -.22 | -.03 | -.05 |
| Total Ant Lobe | -.09 | -.06 | -.01 | -.08 | -.11 |
| Asym Ant Lobe | -.18 | -.00 | -.26 | -.11 | -.12 |

Note: $^{*}p < .05$

Table 4-62

Simultaneous Multiple Regression of the Neuroanatomical Regions on Reading Achievement

| Model[a] | Variables | $R^2$ | Adjusted $R^2$ | $b$ | $\beta$ | $t$ | $p$ |
|---|---|---|---|---|---|---|---|
| a | Sex | .25* | .19* | -4.709 | -.156 | -1.072 | .29 |
| | Total BV | | | .040 | .234 | 1.652 | .11 |
| | Right Planum | | | -6.066 | -.379 | -3.061* | .00 |
| | Left Ant Lobe | | | -6.876 | -.435 | -2.791* | .01 |
| b | Right Planum | .17* | .13* | -4.408 | -.320 | -2.401* | .02 |
| | Right Parietale | | | 2.822 | .170 | 1.277 | .21 |

Note: $^*p < .05$; [a]Dependent variables: a = Word Attack, b = Broad Reading

## DISCUSSION
## CHAPTER 5

This study investigated the relationship among behavioral and neuroanatomical predictors of reading achievement in a group of school-age children. Specifically, relationships between naming speed and other predictors of reading (i.e., phonological awareness, cognitive ability, and processing speed) were investigated to determine how these variables influence naming speed's prediction of reading achievement. In addition, this study also examined specific neuroanatomical regions and their relationship to these predictors. A discussion of the most relevant findings of each research question and the implications of these findings for future research will be discussed in the following sections.

### Research Question 1: Naming Speed and Phonological Awareness

The purpose of this question was to explore the hypothesized independence of naming speed and phonological awareness in predicting variance of reading achievement. There were several important findings. First, in a correlation analysis, significant relationships were found between the Elision task and both the RAN Numbers and RAN Letters tasks. These results are similar to the modest relationships reported in previous studies among samples of both average and impaired readers (Cornwall, 1992; Wolf et al., 2002; see review in Wolf & Bowers, 1999). Other studies have reported no significant relationships (Goldberg et al., 1998; Wolf et al., 2000). Second, in a series of multiple regression analyses, significant contributions of both naming speed and

phonological awareness to reading achievement were found. In addition, the expected pattern of independent contributions of naming speed and phonological awareness on specific measures of reading achievement that have been used in similar studies was not found in this study. In previous studies, researchers have reported that phonological awareness tasks typically contribute the most variance to word attack measures, with a limited, unique contribution of naming speed (Blachman, 1984, Bowers, 1993, 1995; Bowers et al., 1988; Bowers & Swanson, 1991; Cornwall, 1992; Wolf et al., 2002). Conversely, these researchers have also reported that naming speed tasks typically contribute the most variance to word identification measures, with a limited contribution of phonological awareness measures. However, in this study, phonological awareness emerged as the strongest predictor overall, with a limited contribution from naming speed, on all measures of reading achievement, including the basic and broad cluster scores. The limited contribution by the naming speed task may be due in part of its relationship with nonphonological predictors of reading, such as cognitive ability and processing speed. This question was addressed in the next section.

## Research Question 2: Naming Speed and Nonphonological Predictors

Cognitive Ability. The purpose of this question was to explore the hypothesized independence of naming speed and phonological awareness in predicting variance on specific measures of reading achievement when cognitive ability is included. There were several important findings. First, in the correlation analyses, significant relationships were found between all of the naming speed and phonological awareness tasks with cognitive ability. These results are consistent with previous studies involving phonological awareness tasks, however, few if any, have reported the same results for

naming speed (Wolf et al., 2002, see review in Wolf & Bowers, 1999). In their review, Wolf and Bowers indicate that for naming speed, "to date, no evidence of a mediated relationship [by IQ] has been found. The naming speed deficit appears unrelated to IQ." In a recent study, Wolf et al. (2002) report no significant relations between IQ and naming speed. They did, however, report significant relationships between IQ and the phonological awareness measures in their study.

The second important finding, based on a series of multiple regression analyses, is that, on average, both cognitive ability and phonological awareness emerged as significant predictors of reading achievement. Naming speed's contribution was greatly reduced, and at times, made minimal contributions to each model. This finding suggests naming speed may share some overlapping variance with cognitive ability.

Several studies have investigated the relationship between intelligence, rapid naming, and phonological awareness (Ackerman et al., 1990; Bowers et al., 1988; Wolf et al., 2002). These researchers report significant relationships between naming speed and reading achievement, even after controlling for IQ. However, careful analysis of these studies indicates that although naming speed remained significant, the percent of variance it predicted was greatly reduced. For example, Bowers et al. (1988), reported two models for each reading measure: one with IQ and one without. In the first model, the RAN Numbers task predicted 28% of the variance in word identification. However, when IQ was added to the model, although it remained a significant predictor, it only accounted for 11% of the variance. Verbal IQ accounted for 27% of the variance in the overall word identification score. The same pattern was observed for the other reading measures in their study. Wolf et al. (2002) reported that although both the phonological

awareness and naming speed tasks were significant predictors, the IQ estimate accounted for the greatest amount of variance in each of the reading measures. Therefore, based on these observations and the findings in the current study, the relationship between naming speed and IQ needs to be investigated further.

Processing Speed. The purpose of this question was to explore the hypothesized independence of naming speed and phonological awareness in predicting variance on specific measures of reading achievement when processing speed is included. In this study, processing speed was measured using two types of ECTs: Visual IT and three tasks of RT. Interestingly, the Visual IT task did not significantly correlate with many of the tasks. This was the first study to investigate the relationship between predictors of reading achievement and performance on the IT task. Only two other studies have investigated reader group differences on tests of IT (Kranzler, 1994; Whyte et al., 1985). Although a relationship between reading achievement and IT was not found in this study, IT has been found to be substantially correlated with measures of intelligence. Future work should still explore possible connections with performance on this task and measures of reading achievement.

There were several important findings involving RT in this study. First, results of the correlation analyses indicated that the phonological awareness tasks did not correlate as strongly with the RT variables as the naming speed tasks. This finding was surprising, given that Stringer and Stanovich (2000) reported significant correlations between RT and phonological awareness tasks in their study. In their study, the RT task was similar, in that participants were instructed to press a specific pushbutton to match a stimulus. In addition, results of the multiple regression analyses in the current study

indicated that RT added little or nothing to the prediction of overall variance in reading achievement. Stringer and Stanovich (2000) reported similar results in their study; however, they did not investigate naming speed. They suggested that RT explained little variance in reading achievement because of the overlap in variance shared with phonological awareness and cognitive ability. In another recent study, Catts et al. (2002) investigated the relationship between processing speed, rapid naming, and phonological awareness in predicting reading achievement. In their study, they reported that when considered along with IQ and phonological awareness, speed of processing explained unique variance in reading achievement. Additionally, when RT was included in a model with IQ, phonological awareness, and naming speed, RT remained a significant predictor, but naming speed did not. However, there are two important points to be made about their findings. First, Catts et al. used an object naming task as their only measure of naming speed. Research suggests that alphanumeric tasks (i.e., letters or numbers) may involve more automatized naming than object naming tasks (Wolf et al., 1986). Also, some studies have shown that alphanumeric naming tasks are more closely related to reading than nonalphanumeric naming tasks (Schatschneider, Carlson, & Francis, 2002; van den Bos, Zijlstra, & Spelberg, 2002; Wolf et al., 1986). Therefore, it is possible that a relationship with reading might have been found if the RAN Letters or RAN Numbers tasks were chosen instead of the RAN Objects task. Second, the RTs that were used in their study consisted of motor, visual, lexical, grammatical, and phonological tasks. These tasks are not the prototypical RT tasks that are commonly used in studies. For example, a picture naming task was used as a measure of lexical RT, which is very similar to the RAN Objects task. Finally, although Catt et al. reported that RT remained

a significant predictor, the amount of unique variance accounted for by speed of processing was small compared to that of phonological awareness. These results suggest that processing speed is not a primary factor in reading, but it may play a role. Because the current study is only the second study that has investigated the relationship between naming speed, phonological awareness, and processing speed, this is an area of research that needs to be addressed further.

Cognitive Ability and Processing Speed. The purpose of this question was to explore the hypothesized independence of naming speed and phonological awareness in predicting variance on specific measures of reading achievement when both processing speed and cognitive ability are included. There were several important findings. First, several significant relationships were found among the MT variables and cognitive ability. However, this is not surprising, given that Jensen (1982) among others, have found significant correlations with IQ for both RT and MT. In fact, there are studies that have reported the highest correlations with IQ are more often observed with MT compared to RT (Frearson & Eysenck, 1986; Jensen & Monro, 1979). However, it is important to note, that the correlations between IQ and RT reported in this study are smaller than those typically reported. Studies have shown that RT correlates about -.20 to -.40 with intelligence (Rijsdijk et al., 1998; Vernon, 1993). The reason for the lack of significant findings in this study is unclear. Measurement error, restriction of range, order of tasks given, or subject age and fatigue are just a few of the possible explanations.

The second finding, based on a series of multiple regression analyses, indicates that when both cognitive ability and processing speed are entered in each model, both phonological awareness and cognitive ability emerge as significant predictors. The

naming speed task is rarely, if ever, a significant predictor. Again, this supports the finding that naming speed may share some overlapping variance with cognitive ability.

Although Stringer and Stanovich (2000) did not include a measure of naming speed in their study, the results in the current study are similar. For example, when both IQ and the Rosner (i.e., a measure of phoneme analysis) were entered in a regression model with RT to predict word recognition skill, both IQ and the Rosner emerged as significant predictors. Performance on the Choice RT task accounted for only 1% additional variance. However, Stringer and Stanovich's study consisted of adults, and the current study is the first to observe these similar findings in a sample with children. Further research is needed before any definitive conclusions concerning the roles of processing speed can be made.

## Research Question 3: Neuroanatomical Correlates of Reading

In addition to investigating the relationship among the behavioral variables associated with reading, the other purpose of this study was to explore relationships among specific regions of the brain and predictors of reading achievement. Predictions were made based on previous studies, many of which have been done with adults and children diagnosed with learning disabilities. The goal of this question was to explore these same regions in a sample of normal children.

There were several important findings in this study. First, several significant correlations were found between the specific neuroanatomical regions and predictors of reading achievement. In this study, small size of the left and right parietale, large size of the rostrum, and leftward cerebral asymmetry were significantly related to slow performance on the RAN task. In addition, when these areas were entered as independent

variables in a series of multiple regression analyses, both the rostrum and cerebral asymmetry emerged as significant predictors, after controlling for the effects of sex and total brain size. Although these findings are significant, they did not replicate previous findings in the literature. However, there have only been a few other studies that have investigated neuroanatomical correlates of RAN performance (Eckert et al., 2003; Eden et al., 2000). Based on these studies, it was predicted that the size of the anterior lobe of the cerebellum or the pars triangularis might have been significantly related to performance on the RAN. Findings involving the cerebellum and pars triangularis have been the most consistent in research involving structural differences among the brains of the reading disabled population (Eckert el al., 2003). For example, studies of cerebellar function have shown that the cerebellum plays a role in automatization, an important process for fluent reading (Ito, 1984; Nicolson et al., 2001; Stein & Glickstein, 1992).

The fact that the rostrum predicted performance on RAN tasks is interesting, given that previous research is lacking in this area. Few studies have explored the relationship between the size of the corpus callosum and reading achievement. The corpus callosum is the largest bundle of white matter in the brain that aids in communication between the hemispheres. It is possible that disordered interhemispheric communication may play a key role in reading problems. Previous studies using MRI have reported the size of the corpus callosum's subregions may be related to reading problems. For example, Duara et al. (1991) reported a larger splenium and Hynd et al. (1995) found a smaller genu among a sample of dyslexic readers. Others have reported a shorter overall shape of the corpus callosum among a reading impaired sample (von Plessen et al., 2002). Significant size differences in this region have also been reported

among other disabled populations, such as children with Attention-Deficit Hyperactivity Disorder (ADHD). Some of these researchers have reported smaller total and regional corpus callosum areas (Giedd et al., 1994; Hynd et al., 1991), while others have not (Castellanos et al., 1996). Together, these results suggest that structural differences may exist, however further research is needed before any conclusions can be made.

Results of the correlation analyses also indicated significant relationships between the left and right parietale and performance on the phonological awareness tasks. The planum parietale is an extension of the planum temporale into the supramarginal gyrus of the parietale lobe. The planum parietale is typically larger on the right and may be associated with visuospatial processing (Leonard et al., 1993). Previous researchers have reported atypical asymmetry in this area may be related to reading disability. For example, Robichon et al. (2000) suggested that phonologic impairment in dyslexia may be associated with greater planum parietale asymmetry. In the current study, larger surfaces areas on both the right and the left predicted better performance on the phonological awareness tasks. Although these results do not support previous research, they do suggest that morphological differences in this area may be related to phonological awareness. These results can also be compared to research involving the planum temporale. Previous researchers have reported mixed findings involving asymmetry of the planum temporale. For example, Larsen et al. (1990) was one of the first studies to suggest that atypical asymmetry of the planum temporale (right greater than left) is specifically linked to phonological impairment. They showed that a group of dyslexic readers with symmetrical plana were impaired on a measure of nonword reading. However, other researchers have not reported these findings (Eckert et al., 2003;

Leonard et al., 2001). For example, Leonard et al. (2001) found no asymmetry differences among a sample of adults with phonological decoding deficits. These findings suggest that there is a lack of consensus regarding the relationship between the role of the planum temporal and parietale in predicting phonological awareness.

There were also significant relations found between performance on several of the ECTs and size of the neuroanatomical regions. Probably the most notable of all these is the significant relation found between performance on Visual IT and the presence of a duplicated Heschl's gyrus in the left hemisphere. Previous research indicates many individuals exhibit two Heschl's gyri, however they are more often seen in adults and children with phonological decoding deficits. Based on previous findings, it was predicted that a left H2 would be related to slow processing speed and poor performance on the phonological awareness tasks in this study. In two previous studies, Leonard et al. (1993, 2001) found multiple Heschl's gyri among both a sample of children and adults with dyslexia and a sample of adults with phonological decoding deficits. Other studies have reported similar results on processing tests, such as IT (Leonard et al., 1998; Grudnik, 2001). For example, Grudnik (2001) found a significant correlation between performance on the IT task and a duplicated Heschl's gyrus in the left hemisphere among a sample of normal children. Similar results were found in the current study. However, significant relationships were not found with the phonological awareness tasks in this study.

Several neuroanatomical regions significantly correlated with reading achievement in this study. Specifically, significant relations were found between the size of the right planum, right parietale, left anterior lobe, planar asymmetry and performance

on several of the reading measures. In addition, when these neuroanatomical regions were entered as independent variables in a series of multiple regression analyses, several significant predictors of reading performance emerged. For example, both the right planum and left anterior lobe emerged as significant predictors of performance on the Word Attack subtest. Specifically, small size of each of these regions predicted better scores.

Based on previous research, it was predicted that the planum temporale would be related to reading achievement. The findings from the current study can be compared to other studies that have reported relationships between planar asymmetry with both language skills and verbal IQ. In one example, Eckert (1998) studied a group of sixth grade children from a diverse set of public schools, unselected for reading impairment. Eckert found that planar asymmetry was related to performance on both verbal and phonological tasks. However, Eckert also found that a large right planum was strongly related to poor verbal and phonological skills. The results of the current study suggest that a small right planum is related to better performance on phonologically based measures of reading achievement. Although the findings from the current study do not replicate these results per se, they do suggest involvement of the planum in the prediction of reading achievement.

## Other Findings

In addition to the results related to each of the three major research questions in this study, there were other significant findings that deserve mention. First, a significant relationship was found between the age of the participants and performance on both the phonological awareness and naming speed tasks. Significant relationships with age are

expected and support previous findings in the literature involving the RAN task (e.g., Semrud-Clikeman et al., 2000; Watson & Willows, 1995; Wolf et al., 1986; Wolf et al., 2002). For example, Semrud-Clikeman et al. (2000) found a significant relationship between age and performance on several RAN tasks (i.e., RAN Letters, Colors, Numbers, and Objects) used in their study between the younger children (< 12 years old) compared to those of the older age group (> 12 years old). The younger children consistently took longer to name the stimuli than the older children. These findings may be related to the increased exposure to letters and numbers as well as improved RT with age, and suggests the processes tapped by the RAN tasks can slowly become more automatized (Watson & Willows, 1995). In another similar study, Wolf et al. (2002) investigated the relationship among phonological, naming speed, and age variables. In their study, a significant correlation was found between the phonological variables (i.e., Phoneme Elision and Phoneme Blending tasks) and age, but not for the naming speed tasks. Although a significant age effect was not found in their study, Wolf et al. (2002) indicate that there are developmental reader group differences that affect predictions using naming speed tasks. Carver (1991) suggests that average readers reach "asymptotic performance" on naming speed tasks by the end of Grade 2, with no strong predictive naming speed relationships found with reading among average readers from Grade 2 on. However, Wolf et al. (2002) point out that most impaired readers do not fully reach their potential by this point, making RAN tasks a continuously good predictor of reading. Therefore, because a significant relationship was found between age and several of the naming speed and phonological awareness tasks, it was included in all of the multiple regression analyses involving these tasks.

The second important finding was a significant relationship between handedness and one of the neuroanatomical variables, the left pars triangularis. Specifically, the non-right handers in this study had a significantly smaller left pars triangularis than the right handers. Although it is possible that this one significant relationship was related to chance, there is previous work that has investigated handedness differences for this region in the brain. In one such study, Foundas, Eure, Luevano, & Weinberger (1998) found that the right handers in their study had a significant leftward asymmetry of this region (left > right), whereas, the left handers had a reduced asymmetry. These results can be compared to the findings in the current study. It is possible that the non-right handers in the current study had reduced asymmetries, given that the size of the left was not much greater than the size on the right. Although the current results suggest that the mean asymmetry of this region did not differ between right and non-right handers, significant differences may have been found if it was analyzed differently. For example, Foundas et al. (1998) used Analysis of Variance (ANOVA) in their study with hemisphere (left and right) as the dependent variable and handedness group (right- and left-handers) as the independent variable to demonstrate significant hemispheric differences. Therefore, it is likely that some directionality was lost by comparing calculated mean asymmetry between these groups, and this may explain why significant asymmetry differences were not found in the current study.

## Limitations

A brief discussion of the limitations of this study deserves comment. First, as noted previously, the sample was slightly restricted in range. The overall *SD*s for BCA and Broad Reading in this study were slightly lower than the *SD*s reported for these

measures in the general population. However, overall performance on both the cognitive and reading achievement measures ranged from slightly below average to very superior. It is possible that the results of this study would have been different had children with a wider range of ability been included, or children with reading deficits.

Also, in this study, SES was not related to any of the cognitive ability or reading measures. Throughout literature, consistent relationships have been reported between measures of SES (i.e., parental occupation, education, and income) and both intelligence and reading ability (Kamphaus, 1993; Sattler, 1992; Schonhaut & Satz, 1983). In this study, SES was calculated using the Hollingshead four factor index of social status (Hollingshead, 1975). Information on parent education and occupation was obtained and used to calculate the SES score. However, the occupation component was based on job title, and information regarding actual incomes was not obtained. A relationship may have been found in this study had actual incomes been used or other indicators (e.g., free and/or reduced lunch status) been included in the calculated SES score.

In addition, early interventions, such as Head Start, may counteract the effects of SES. Research on the effectiveness of Head Start programs indicate significant and meaningful gains on standardized IQ and achievement tests following one year of intervention (Haskins, 1989). Other research has shown some superiority in achievement test scores by program children, in grades three through six (Bouchard & Segal, 1985). However, these same researchers have shown that while school accounts for some of the variance in intelligence test scores, the effects of family are as potent. It is possible that children in Head Start programs show the most gains primarily during the phases of intense intervention (Bouchard & Segal, 1985). Although information regarding

preschool experience was not collected in this study, it is possible that some of the children received early interventions, thus improving their overall ability and achievement levels.

Validity refers to the extent to which the interpretation of the results of the study can be based upon the statistical measures chosen (Cook & Campbell, 1979). One way to increase the overall power of a study, or the ability to detect an effect when it truly exists, is to increase the overall sample size. There were 57 total participants in this study. However, on several of the measures, missing or incomplete data caused the sample size to drop closer to 50. It is possible that more significant effects would have been observed if the sample size was larger. In addition, several outliers were dropped from some of the analyses, and hence the sample sizes for these measures were also reduced.

Few neuroanatomical regions predicted specific reading skills in this study. It is possible that relationships with reading cannot be limited to one region in the brain. The neuroanatomy involved in the reading process is more likely to be dispersed broadly and not located in one specific region. In addition, the specific skills that are measured by these reading tasks may be more sensitive to age, environmental influences (e.g., instruction or exposure to language), and genetics, rather than neuroanatomy alone.

## Summary and Future Directions

The results of the current study indicate significant contributions of both naming speed and phonological awareness to the prediction of reading achievement. However, the results also suggest that cognitive ability is an important predictor of reading achievement and may share some overlapping variance with naming speed. These findings support Wolf & Bowers' (1999) view of an underlying cognitive nature of

naming speed, beyond those required of phonological processes. This study investigated the relationship between naming speed and other nonphonological predictors of reading, such as processing speed and cognitive ability. The results indicated that naming speed shares some overlapping variance with cognitive ability, but appears unrelated to processing speed. Future work is needed to explore the relationship between naming speed and other nonphonological predictors of reading, such as fluency and attention.

The neuroanatomical findings in this study suggest significant relationships among regions in the brain and predictors of reading achievement. However, it is more likely that variability in reading skill can be better accounted for by a combination of behavioral and biological factors. Continued research, including both neuroanatomical and genetic profiles, may yield important neurobiological indicators of reading skills. These indicators may help identify children predisposed to reading deficits and facilitate early interventions specifically designed to prevent reading disabilities.

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Jennifer L. Mockler, formerly Jennifer L. Grudnik, was born in New Port Richey, Florida, on June 14, 1976. She attended private school in Tampa for both grade school and high school. In 1994, she was named Valedictorian of her high school graduating class. Jennifer attended the University of South Florida, where she earned a Bachelor of Arts in secondary science education-biology. After graduation, she began the school psychology program at the University of Florida, where she received a Master of Arts in Education three years later. During that time, she gained experience as a research assistant at the University of Florida McKnight Brain Institute, studying brain-behavior relationships in children and adolescents. She also taught several courses to undergraduate students in the College of Education. Jennifer became a doctoral candidate in December of 2001. She completed her pre-doctoral internship in the Broward County School District in May 2003. Jennifer is married and lives in Miami, Florida. She currently works as a school psychologist for the Broward County School District.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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